BRITISH CHEMICAL ENGINEERING

# DIGEST

## of Technical and Industrial Developments

### An Atomic Paper Mill

HARWELL started a fashion for the experimental space heating of buildings based on radiators which are warmed by the heat generated in an atomic pile. Norway looks like being the first country to use heat generated by fission for an industrial purpose other than electric power production. A reactor, fuelled with natural uranium and moderated by heavy water, is being built alongside a paper mill at Halden, which lies to the south of Oslo. This will be working in 1957. Its output of heat (equivalent to 20,000 kilowatts) will give sufficient steam to maintain the wood-cooking process carried on in the paper mill. The cost of the steam may be slightly above normal, but this factor in such countries as Norway has to be balanced against the existing heavy pressure on the electricity supply and the fact that much coal and all oil have to be imported.

### Tonnage Oxygen at Scunthorpe

A CENTURY ago Bessemer introduced his new process of making steel from pig iron by blowing with air, and his patent claim allowed for the use of oxygen as an alternative gas. Because of the relatively recent availability of methods of making oxygen cheaply and the development of experience in its use in the steel industry for process purposes, the application of oxygen to the conversion of iron to steel is only just beginning to make headway in Great Britain.

This is further emphasised by the announcement that a large medium-purity oxygen plant is to be built by British Oxygen at Scunthorpe to serve local industries and should be operating in 1958. The reputed capacity is 200 tons of oxygen a day, i.e., about five million cu. ft. At Scunthorpe there are three substantial steel producers and one steel foundry in close proximity, with a combined output of 6,000 tons daily of steel, and this makes the town a suitable place for a new plant.

Furthermore, there is nearby the synthetic ammonia plant of Nitrogen Fertilisers Ltd., which will take nitrogen from the air separation factory at the rate of about one million cu. ft. daily. This represents approximately 5% of the nitrogen available from the factory.

On the process side, steel producers are making increased use of oxygen for flame enrichment in the open hearth furnaces. The Redbourne works of Richard Thomas and Baldwins Ltd. already has plant for the oxygen desiliconisation of pig iron, which is a step in the treatment of pig iron before refining in the open hearth furnaces.

A number of possibilities exist for the useful application of oxygen to steel-making in Scunthorpe, but there has been no public statement covering all the changes of practice which are likely to be made when cheap oxygen is available. The principal outlets appear to include those already mentioned, and in order of use in the stages of conversion from molten pig iron to finished steel in the open hearth furnace are: first, desiliconisation; second, flame enrichment; third, decarburisation. In all cases this refers to basic open hearth practice. At the steel foundry of Firth-Brown Ltd., which uses steel scrap, oxygen will be applied in the electric arc furnace and the Bessemer converter.

### More Nitrogen for British Farms

NEWS of Fisons plans to build a new factory at Stanford le Hope is a reminder of how the demand and supply of nitrogenous fertilisers has increased enormously since 1939. This plant, which will cost about £4½ million, is scheduled to start producing at the end of 1958 at the rate of 49,000 tons of nitrogenous fertiliser a year. This factory will take ammonia from Shell and its output will be sufficient to treat two million acres of farm land. In 1938, the total amount used by all the farms of Britain was only 60,000 tons. During the war annual consumption rose to just over 180,000 tons, and in 1954 the figure was no less than 248,000 tons. It has been estimated that at least 450,000 tons could be profitably used in British agriculture. For wheat, the additional yield that results if the crop is given all the nitrogen it can utilise averages out at about 4 cwt. an acre.

Canadian experience in this connection is very striking, and Sir Alexander Fleck gave some impressive statistics in his recent address to the Canadian Club of Montreal. He said that the last Canadian wheat harvest was 2.6 million tons as against a pre-war crop of 1.64 million tons, though the acreage involved had only increased by 10%. The yield per acre had increased from 33.6 bushels an acre up to 48.2, partly due to the use of better varieties of wheat, but mainly due to heavier applications of nitrogenous fertilisers.

### Irradiated Chemicals

JUST four years after the original discovery by Dr. Arthur Charlesby that ionising radiation could effect cross-linking in certain polymers, three British firms have opened irradiation laboratories to test on a pilot scale the possibility of applying such methods in industry. Tube Investments Ltd. who secured Dr. Charlesby's services to look after their laboratory, and British Insulated Callender's Cables Ltd. are both using two million volt Van de Graaf machines imported from the U.S.A. as the main source of radiation. Monsanto Chemicals are experimenting with a radioactive cobalt

source at Newport. Although in the first instance Tube Investment's equipment will be used for a thorough study of radiation effects on polymers such as polythene, nylon and rubber, other applications are envisaged. Two possible ones are the cold sterilisation of heat-sensitive drugs and the manufacture of transistors.

Callender's will use their machine for irradiating polythene cable insulation on cables. Irradiated polythene is stronger, has a higher softening point and unimpaired electrical properties. In the United States, General Electric is already producing 2½ tons a week of irradiated polythene insulating tape for cables.

## Reinforced Plastics for Chemical Use

LAMINATES made from phenolic resins reinforced with glass fibre retain a considerable proportion of their original flexural strength at temperatures as high as 350° C. The laminate quickly blackens at these temperatures and will retain the load only for about half an hour before failure. The same laminate will operate indefinitely at 180° C. This information was given by Mr. L. H. Vaughan of Bakelite Ltd., at a recent meeting of the Chemical Engineering Group of the Society of Chemical Industry.

The relatively high working temperatures of these new phenolic laminates suggests that they should have fairly wide applications in the chemical industry, although it must be stressed that the only tests which have been carried out so far refer to small samples fabricated under laboratory conditions. It was estimated that the samples contained less than 5% voids. An important application will probably be for the construction of pipelines to carry hot corrosive liquids. A particularly promising idea is to line the reinforced phenolic plastic with a highly resistant layer of polythene or similar thermoplastic.

The great advantage of the phenolic resins is their relatively low cost—of the order of 7d. per lb. This advantage is partly masked in the resin laminates by the high cost of glass fibre, which amounts to about 4s. 3d. per lb. Roughly 50% glass fibre is normally used. The laminate has the advantage of simpler forming techniques than corrosion-resistant metals and comes into its own when complicated shapes are required. It is also considerably lighter than metal of the same strength, which gives it a significant advantage for the construction of overhead pipelines.

## Germany's Largest Oil Plant

ESSO is to build an oil refinery which will be Germany's largest. Its initial throughput will be three million tons, to be increased to five million by 1961. It will be sited north of Cologne, and a £13 million pipeline will connect it with Rotterdam or Wilhelmshaven. Esso is contributing 40% to the pipeline's cost, and other international oil companies will share the rest. According to Herr Geyer, chairman of German Esso, 40% of output will be heavy fuel oil and 36% gas oil and medium fuel oil. Petrol and jet fuel will add up to 18% and the remaining 6% represents gases and waste products. The refinery will operate the hydroforming process. Herr Geyer has stated that the refinery will go one step further and transform part of the petrol obtained into gaseous raw materials for the chemical industry.

## High Density Polythene

PROMPTED by the fact that the polymer produced in the low-pressure Ziegler process possessed certain desirable properties not found in ordinary polythene made by the high-pressure polymerisation of ethylene, I.C.I. began experiments about a year ago to see whether it was possible to obtain new properties in the product by modifying the details of their process. This work has proved highly successful. A modified process, which is covered by a new set of patents, is now being operated to yield the material called "Alkathene" HD—a high-density polythene which is less flexible than ordinary polythene. There are other points of difference. For example, the softening point of Alkathene HD is 33° C higher and it can therefore be sterilised by heat.

Articles injection-moulded or extruded from Alkathene HD can be heated without distortion for 15 minutes at 110°C, whereas similar articles of flexible "Alkathene" collapse after the same treatment. The chemical industry is already making good use of polythene piping, and pipes made of high-density Alkathene will represent a distinct advance as they will be able to withstand higher working pressures and temperatures.

The properties of Alkathene HD are compared with those of standard polythene (Alkathene 20) in the following table:—

| Property | Alkathene HD | Alkathene 20 |
|---|---|---|
| Melt flow Index (Grade Number) ... | 0.7 | 20 |
| Density ... ... ... ... ... | 0.940 grams/cc. | 0.92 grams/cc. |
| Ultimate Tensile Strength ... ... | | |
| Straining Rate 6"/min. ... ... | 2,580 p.s.i. | 1,600 p.s.i. |
| " " 12"/min. ... ... | 2,750 p.s.i. | 1,580 p.s.i. |
| " " 18"/min. ... ... | 2,900 p.s.i. | 1,500 p.s.i. |
| " " 30"/min. ... ... | 3,200 p.s.i. | 1,400 p.s.i. |
| Elongation at Break | | |
| 6"/min. ... ... | 380% | 450% |
| 12"/min. ... ... | 300% | 490% |
| 18"/min. ... ... | 200% | 490% |
| 30"/min. ... ... | 180% | 500% |
| Vicat Softening Point ... ... ... | 116° C. | 83° C. |
| Stiffness Modulus at 20° C. ... ... | 5 × $10^4$ p.s.i. | 2.6 × $10^4$ p.s.i. |
| Environment Stress Cracking Test (I.C.I. test using Lissapol N) .. | 1.75 hours | 0.25 hours |
| Low Temperature Brittle Point ... | below—70° C. | —30° C. |

During 1956, one to two hundred tons of "Alkathene" HD will be available, mainly for trial purposes at home and overseas. It is intended to establish commercial manufacture on a progressively increasing scale, although it may not be possible to meet all demands for some time, particularly in face of the constantly increasing demands for the conventional product. Initially, the price of "Alkathene" HD will be 4s. per lb. independent of quantity. Compounds with carbon black or anti-oxidant, or both, will be made available at increased prices.

## Lack of Chemical Engineering Research

THE latest annual report of the Department of Scientific and Industrial Research shows all too clearly how little Government sponsored or supported research work is carried on in chemical engineering. In the Government research departments only marginal aspects of chemical engineering have received attention: for example, the Fire Research Station has carried out work on methods of extinguishing chemical fires; the Chemical Research Laboratory at Teddington has been

working on new methods of controlling corrosion and on the possible recovery of germanium from ammoniacal liquor; the Fuel Research Station has a programme of research on the Fischer-Tropsch process and the Mechanical Engineering Research Laboratory at East Kilbride is undertaking work on heat transfer.

The research associations, which are mainly supported by contributions from firms in industry but also receive a grant from the Department of Scientific and Industrial Research, are investigating a number of more specialised problems in chemical engineering: for example, at the Leather Research Association work is being conducted on drying leather, at the Electrical Research Association on heat pumps, and at the British Hydromechanics Research Association on the hydraulic transport of coal.

These are marginal problems, however, compared with those which could be undertaken by a Government chemical engineering research laboratory or chemical engineering research association. Although there have been suggestions from time to time that such a research association should be set up, it seems that there is no immediate likelihood of its being formed.

## I.C.I. Transfer Scholarships

IT is estimated that about 25% of students who pass from school to university have a definite leaning or aptitude for science and technology. An approximately equal number of students are wholeheartedly interested in art subjects. Is it possible to attract some of the remainder who did not specialise in science at school to take science degrees? I.C.I. is convinced that such a switch is feasible, and to encourage students to make the transfer it has decided to provide annually over the next few years about 50 scholarships of a new type.

These I.C.I. "Transfer Scholarships" will make it possible for students to take a preliminary science course of one year's duration at certain universities, and then go on to take normal Honours science courses. The scholarships will be available for the first time during 1956/57 at Cambridge University; Imperial College, London University; King's College, Durham University (Newcastle); Liverpool University; and Oxford University. The value of the scholarships will be based on State Scholarship rates, there will be no "means test."

The scheme, which should produce 40 to 50 additional scientists or technologists per year, is certainly a step in the right direction and we shall be surprised if this idea is not taken up by several other big firms.

## Antibiotics for Food Preservation

LARGE quantities of antibiotics are already being used in connection with food production, to boost the growth of pigs and chickens. Now, experiments are being made in several countries, including Britain and America, to see whether antibiotics can be safely used on the large scale to lengthen the storage life of meat and fish. The Food Investigation Organisation of the D.S.I.R. is carrying out such tests.

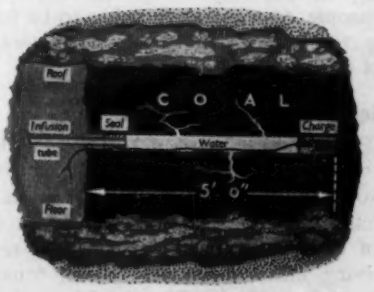
For example, the laboratories of the Torry Research Station, Aberdeen, report that haddock and cod have been kept in good condition for seven to ten days longer than usual, by adding a few parts per million of an antibiotic to the ice in which the fish is packed. These experiments are being extended by pilot scale tests on board the Department's experimental trawler. This additional storage life, if proved effective on this scale, will give a great advantage to the fishing industry in the longer voyages possible, and the greater retention of quality for the consumer.

The most effective antibiotic found is chlortetracycline (known in medical practice as aureomycin), which is rapidly destroyed in subsequent cooking. There are, however, good medical reasons for avoiding the widespread and general use of a drug used for combating human disease. Nevertheless, there should be other antibiotics of the same general type which, though equally effective, have not these medical objections. These substances are of course expensive, but would only require to be used in very small amounts and be relatively easy of application.

By the state of the law relating to food preservatives in Great Britain, the use of any antibiotics is illegal. A regulation permitting their use in a strictly limited application has just been made in the U.S.A. However, for similar applications in this country, our health authorities will have to be satisfied that the procedures are safe.

## A New Blasting Technique

THE Nobel Division of I.C.I. has developed a new method of blasting coal. Called "pulsed infusion shotfiring," this depends on the use of water to spread the force of the explosion more effectively. The water also serves to lay the dust which is produced, and to eliminate the risk of fire damp explosion. The principle of the technique is as follows, to quote from official description. First a hole is bored into the coal and an explosive charge inserted. Then an infusion tube is pushed into the collar of the hole. This device consists essentially of a tube and a gland. It performs a dual function: it introduces a supply of high-pressure water into the hole and also acts as a sealing plug. Pressures of up to 1,000 lb./sq. in. are employed, but more typical




figures range from 300 to 400 lb./sq. in. The water then penetrates into the surrounding coal, filling up any slips or breaks. Under this pressure a shot is fired with a submarine detonator, and the impulse of the explosion is transmitted through the water mass, thus breaking down the coal. The explosive energy is harnessed far more efficiently than when blasting in the conventional manner "in the dry," and in addition the quality of coal breakage is better. A special "permitted" explosive

had to be developed to meet the demands of this technique and has been named "Hydrobel." Its composition is such that it will work reliably under the high hydrostatic pressure involved. Fifteen collieries are now using this blasting technique regularly, and it has been demonstrated to mining engineers from six countries overseas.

## The Talent Circus

THE acute shortage of technologists and scientists has intensified the competition between industrial firms for the limited amount of "fluid" talent to an almost fantastic level. The "circus" of industrial representatives who go round the country seeking staff among those about to take their first degree is now an accepted feature of university life, and only when the shortage disappears will professors' waiting rooms become less crowded. We know of one British firm which has studied the costs of all the measures it has been forced to adopt in order to be able to recruit its fair share of scientific and technical men, and it reckons that the total expenditure averages out at £4,000 for every new recruit they obtain.

The competition is made fiercer in certain fields because American firms are also bidding. One U.S. company thinks nothing of flying over possible candidates for a weekend and an interview in New York. A correspondent to *The Times* throws the oddest sidelight on this great scramble for talent: "One physicist I know has spent every weekend since he came down from the university voyaging up and down the country in first-class compartments to interviews, lodging at four-star hotels, dining with directors and drinking more than is good for him. He has no intention of taking any of the posts he is offered, since he is very well placed already, thank you. But these weekly outings have become a hobby with him."

Industrial firms cannot be criticised for going to extreme lengths to obtain essential staff, and there is no alternative to the scramble for talent short of "drafting" new graduates army-fashion, as we understand happens in Russia. The aim must be to end this shortage of qualified people. Maximum effort has to be focused on expanding the training facilities in universities and colleges of technology.

## Antibiotics Against Corrosion

COULD antibiotics be used to check underground corrosion due to sulphate-reducing bacteria? Recent work at the Chemical Research Laboratory, Teddington, has led to the suggestion that a metabolic product of a species of actinomycete was responsible for preserving metal tools and objects found during excavation at Chew Stoke. The mould grows freely on tannins, which were claimed by the same laboratory a few years ago to be themselves corrosion inhibitors. If this new claim can be substantiated, corrosion engineers will have a new method of attack to consider.

Most of the known antibiotics are derived from organisms which exist in the soil. Tests of seven of these have shown little or no effect on sulphate-reducing bacteria. Only aureomycin and chloramphenicol show any effect at low concentrations. The final identification of the inhibitor at work at Chew Stoke will be awaited with interest.

## Catching Them Young

HOW many schoolboys and girls ever give a thought to making a career in the chemical industry? In regions where the industry is concentrated, the figures are reasonably good, but elsewhere interest is probably very low. The achievements of industrial chemistry do not get much attention in the national press and on the radio, where the technologies which steal most of the thunder are nucleonics, electronics and rocketry. Good chemistry masters arouse tremendous enthusiasm among their pupils, and the industry needs to capitalise on this fact. Some firms do so by providing schools with literature and wall charts, as a form of "prestige advertising". Now the industrialists have taken collective action, and the result is a well produced booklet entitled *The Chemical Industry Calling You!* This has a very human appeal because it gives a number of case histories of real though anonymous men now working in chemicals, and it should certainly help to boost recruitment. The huge range of different jobs that the industry offers is also well conveyed in this publication of the Association of British Chemical Manufacturers (86 Strand, London, W.C.2), which has gone to employment exchanges and schools all over the country.

## Expanding Titanium Production

THE U.S. titanium industry continues to expand, and while the amount of titanium produced in 1955 (7,200 tons) is small compared with the output of other structural metals, it represents a satisfactory advance over production in previous years. I.C.I's last production figure was 1,500 tons a year. The Americans anticipate that in 1957 the capacity of the industry should be 22,500 tons a year. The high price of titanium (about $3.45 as against I.C.I.'s price of 21s. per lb.), still limits its wider application, but new processes and expansion of existing proces for the production of the metal should reduce it.

## Will-o'-the-Wisp

EACH year about 1,250 million cu. ft. of methane are drained from sixteen British coalmines. The quantity of gas involved is now so large that methods of using it have become important. According to the report of the European Production *Agency Drainage and the Use of Methane from Coalfields*, Britain may eventually tap almost ten time as much by drainage. At the moment most of the methane is used at the pits to fire boilers or run auxiliary gas engines, although some is bottled and Welsh Gas Board is taking from the Point of Ayr Colliery 3 million cu. ft. of firedamp a week for conversion in a Onia-Gegi cyclic catalytic cracking unit to boost the coal gas supply. The use of methane as a fuel may seem wasteful, but it is a simpler business than making use of firedamp drained from the pits as a chemical raw material. Individual sources in Britain appear to be much to small and unsteady to offer much promised of chemical development, although conditions in the Saar make prospects there look rather different.

# *Victoria Instruments*

# DEWPOINTMETER

Developed by British Coal Utilisation Research Association

**SPECIFICATION:**

The instrument consists essentially of a high quality Pyrex glass detector element bearing 2 Pt / Pt 13% Rh thermocouples in the hemispherical surface, and mounted on a probe 1 inch in diameter and 6 ft. long. Cooling air and compensating leads from the other end of the probe connect to a box (24 in. x 10 in. x 6 in.) of good quality hardwood fitted with Rototherm, double range voltmeter and millivoltmeter and a 5 range microammeter. All these instruments are first grade accuracy (B.S.S. 89) having spring mounted movements and are built into a single unit which is internally earthed.

Cooling air connections are of the "Instantair" type and all metal parts are chromium plated. Calibrations can be made in English or Metric units.

Overall weight—

| | | |
|---|---|---|
| Probe and leads | ... | 8 lb. (4 Kg.) |
| Box ... ... | ... | 30 lb. (14 Kg.) |

**BRIEFLY, the Instrument:**

The probe is inserted into the gases under test and the detector element temperature is controlled by the admission of cooling air from some suitable source (e.g. a small compressor) to its underside. The two thermocouples measure this temperature. When the surface is cooled below the dewpoint of gases they also become the electrodes of a "cell", the conductivity of which is recorded on the microammeter.

The detector element is constructed in such a way that its temperature can be controlled at fixed temperatures below the dewpoint for long periods, and comparative measures of the amounts of sulphuric acid condensed out at any selected temperature can be made.

The instrument is of particular value in determining the temperature range over which corrosion by sulphuric acid may be expected.

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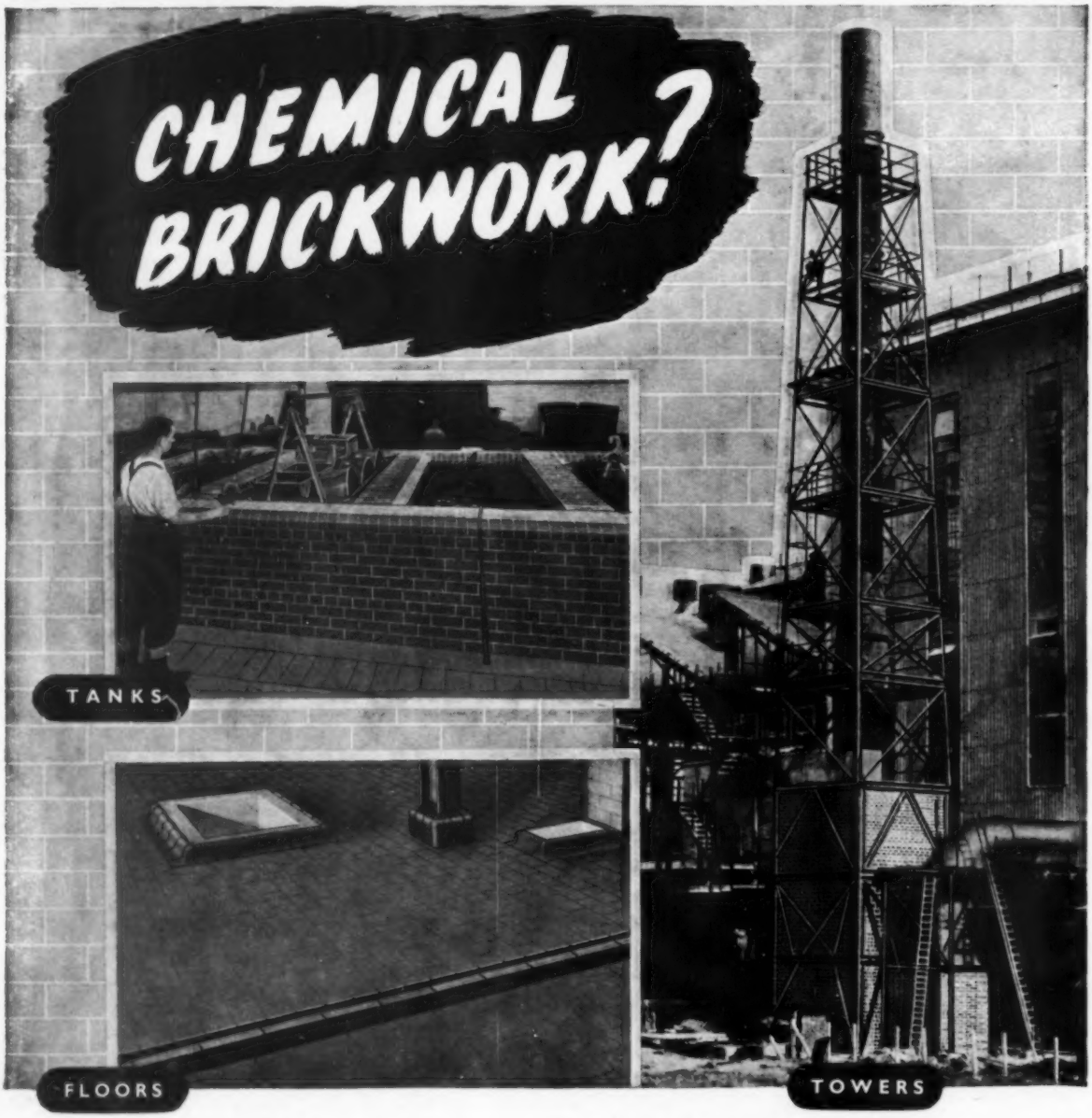


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BRITISH CHEMICAL ENGINEERING
A HEYWOOD TECHNICAL PUBLICATION

# A Technology without Boundaries

THIS is a propitious time for launching a new journal devoted to the many aspects and applications of chemical engineering. The prophets like George E. Davis, who argued the case that chemical engineering was a separate technology with an indispensable part to play in the chemical and allied industries, are now fully honoured in their own country. The general attitude in Britain towards the subject has improved out of all recognition in a few years, and its great importance is now widely appreciated by industry, Government and the universities.

Chemical engineering is nowadays regarded as the fourth primary technology. It ranks alongside civil, mechanical and electrical engineering. We hope to see that point given official recognition in Britain within a few months by the granting of a royal charter to the Institution of Chemical Engineers. The chemical industry is now thoroughly aware that many of its design and production problems can only be solved satisfactorily by the chemical engineer. But the special techniques he has developed can be applied in many other fields far removed from chemical manufacture. As Sir Harold Hartley has said, chemical engineering is intimately involved in supplying all the major needs, whether they are food, fuels and energy, water, metals, materials or drugs.

The rapidity with which new techniques and applications are being developed makes it difficult for everyone to keep pace with even the major advances, and our aim shall be to keep readers abreast of all the developments of major importance. Here the emphasis will be placed on those developments which impinge on more than one sector of industry. Similarly, in our articles describing new processes, the emphasis will be on those which have reached the production stage. Already, however, we have found an encouraging demand among subscribers for information about new work which is only in the research or development stage, and we shall certainly do our best to meet that demand.

We take the view that chemical engineering is one of the key technologies upon which prosperity depends in the new Industrial Revolution; it is as vital to Britain as both nucleonics and electronics. The country's economic position makes obligatory the fullest possible exploitation of all its techniques, and we shall give constant attention to all the various ways in which their application can be widened. These techniques can augment production in many old established industries, and we regard them as absolutely basic to the development of such new lines of production as petrochemicals. Chemical engineering in action can contribute greatly to the increased productivity which our country's economic situation calls for. The chemical engineer can help Britain to derive the maximum benefit from British discoveries and inventions. By fully engineering our new productive ideas, Britain can earn more money abroad on patents and know-how, while our plant manufacturers and contractors will be able to increase the revenue which their goods and services obtain in the export market.

At home the trend towards the fullest exploitation of these techniques makes for economy in labour, a vital consideration when manpower is scarce. In this context advances in process control are supremely important, especially where they make automatic control practicable. There is a great demand for news of progress in this field, and we believe regular publication of such information can be doubly valuable as it can help to bridge the gap between the instrumentation experts and the chemical engineer, besides providing a link between the manufacturers and users of such equipment.

By a happy coincidence this month brings the celebration of Perkin's epoch-making discovery, which was the starting point of the whole synthetic organic chemical industry. Another important anniversary which is almost upon us is the 75th anniversary of the Society of Chemical Industry. Both occasions will prompt reviews of the great progress made by the industry, and any stock-taking must make it clear how greatly the major industrial achievements have depended upon the quality of their chemical engineering content. The S.C.I.'s chemical engineering group has done much to foster this technology, not least by encouraging publication of British results when the tendency was to rely increasingly on foreign books and periodicals for reports of progress in this field. The tide is now flowing strongly in the opposite direction. British literature on chemical engineering is becoming more and more abundant, and it is a sign of the times that our first issue appears within a few weeks of the publication of the first volumes of the first British "encyclopedia" on chemical engineering. First-class journals can do as much to enhance national prestige in this technological age as any kind of literature, and in flying the banner of British chemical engineering as our title we accept the full responsibility of producing a journal which will stimulate technical progress and increase the reputation of our engineers and manufacturers throughout the world.

*Fig. 1. One of the two pile stacks, 415 ft. tall, at the Windscale Works. The elevator is used for regular inspection of the filter chamber at the top.*

# Chemical Engineering Achievements at Windscale

by G. R. HOWELLS, M.B.E., B.Sc.

THE Windscale Works of the United Kingdom Atomic Energy Authority is situated at Sellafield on the West Coast of Cumberland, and was designed and constructed between 1948 and 1952 for the manufacture of plutonium. The plutonium is formed in nuclear reactors, and subsequently separated from the irradiated uranium. The design and construction of suitable plants for the processes necessary for this separation introduced new and formidable problems in chemical engineering.

Nuclear reactors make use of the chain reaction which occurs when a neutron strikes a U235 nucleus causing fission, and the emission of a further 2.5 neutrons together with a large release of energy. One neutron is used to continue the chain, one is captured by U238, the remainder are lost by capture in poisons or constructional materials or are used for control purposes. The U238 is converted to unstable U239 which decays via neptunium to plutonium.

Thus, by the nature of the fission process, the plutonium is formed in irradiated uranium together with an approximately equal weight of fission elements. These "fission products" comprise some thirty elements to be found in th middle of the Periodic Table and they vary widely in their chemical properties, ranging from the noble gases krypton and xenon to the very reactive iodine. They are mostly unstable, with half lives varying from seconds to many years, and their radiations are biologically harmful. The alpha and beta rays are particles of high energy with considerable local destructive effect, whereas the gamma rays, being electromagnetic in character, have the ability to penetrate a considerable thickness of all materials. Protection against alpha and beta emitters is largely one of containment, while a gamma emitter requires to be placed behind a biological shield wall of sufficient density and thickness. Operational factors required that the uranium fuel would be discharged from the reactor when the plutonium concentration had reached a level of about 300 p.p.m., but even so many hundreds of thousands of curies of radioactive elements would be produced daily. The high cost of manufacture and the scarcity value of plutonium, the low utilisation of uranium in a single cycle, and the high toxicity of the fission products, all affected the problem.

The separation processes at Windscale had thus to meet the following specifications: (1) to recover plutonium in a pure form with an efficiency greater than 99.9%; (2) to reduce the uranium concentration in the plutonium to a few parts per million; (3) to reduce the fission product radioactivity in the plutonium by a factor of $10^8$; (4) to recover the uranium in a pure form free from fission products and plutonium; (5) to arrange that fission

products be in a form suitable for permanent storage; and (6) to ensure that the emission of fission products to the atmosphere or effluent system would not create a hazard.

## Development of the Process

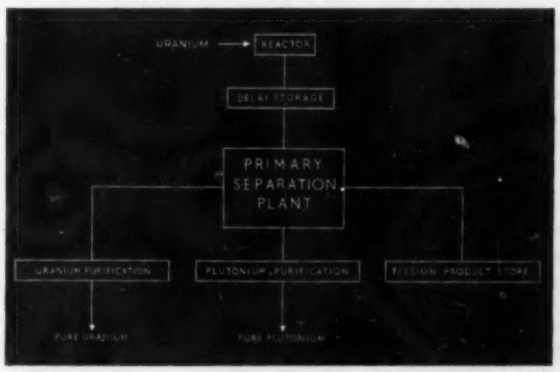
In 1947, when the requirements were first postulated, there were no laboratories in this country suitable for the proper development of such chemical processes. Facilities were however made available by the Canadian Government at their Chalk River establishment together with a few milligrams of plutonium and some aged fission products. It was known then that a process involving co-precipitation of plutonium with bismuth phosphate had been used in the U.S.A., and information was available on precipitation processes using lanthanum fluoride. These processes were rejected, however, because of the difficulty of handling solid/liquid separations in the presence of radioactive materials. The other processes that were considered were based on ion exchange, high-temperature distillation, and selective solvent extraction. The solvent extraction process showed most promise of developing into a suitable system for large-scale operation, and so the limited research effort which could be mounted was concentrated on it. I.C.I. Ltd. set up a team at Widnes to co-operate in this work, with the special responsibility of preparing suitable flow-sheets and developing equipment. Later, with the completion of the Radiochemical Laboratories at Harwell, a more detailed study was possible of the chemistry of plutonium, fission products and plant systems.

In order to integrate the research, design, and construction programmes, it was necessary to state in broad outline the requirements of each process before the results of the development work became available. Great flexibility was thus required so that changes which the development work showed to be necessary could be incorporated at a later date. The scheme shown in Fig. 2 was adopted. The irradiated uranium would be allowed to decay so that its short-lived activity dies away, and would then be processed in a Primary Separation Unit. In this unit the main separation process would be carried out, and there would be three outgoing streams: (1) the plutonium in small bulk and suitable for final purification; (2) the uranium ready for purification; and (3) the fission products in a form suitable for permanent storage.

Clearly the key to a satisfactory over-all process is the successful operation of the Primary Separation Plant, and for this it was decided to use a solvent extraction process. The extractability of plutonium in a solvent system depends upon its valency state, the acidity and the concentration and type of salts present. By suitable adjustment of extracting conditions, it was possible to evolve a process which achieved what was required. The extraction of aqueous nitrate solutions using the solvent dibutyl carbitol was chosen as the basis of the process carried out in the following stages (see Fig. 3): (1) the irradiated uranium is dissolved in nitric acid to give a solution of the nitrates; (2) uranium and plutonium are extracted into dibutyl carbitol in Extractor 1, leaving the fission products in a form suitable for storage; (3) the solvent solution is neutralised and the plutonium reduced; (4) the plutonium is washed from the uranium solution in Extractor 2; (5) the uranium is recovered into aqueous solution in Extractor 3 and is ready for the purification process; (6) the plutonium is oxidised to the extractable form; (7) the plutonium is further purified by extracting into dibutyl carbitol in Extractor 4; and (8) the plutonium is recovered into aqueous solutions in Extractor 5 ready for the purification process.

## Factors Influencing the Design

Radioactive materials emitting gamma rays must be placed behind biological shielding, so there can be no direct approach for operation, cleaning or maintenance of the processing plant. During the design stage, it was thought that once plant containing high levels of activity had been put into operation it would be impossible to decontaminate it sufficiently to allow free access: this meant that there



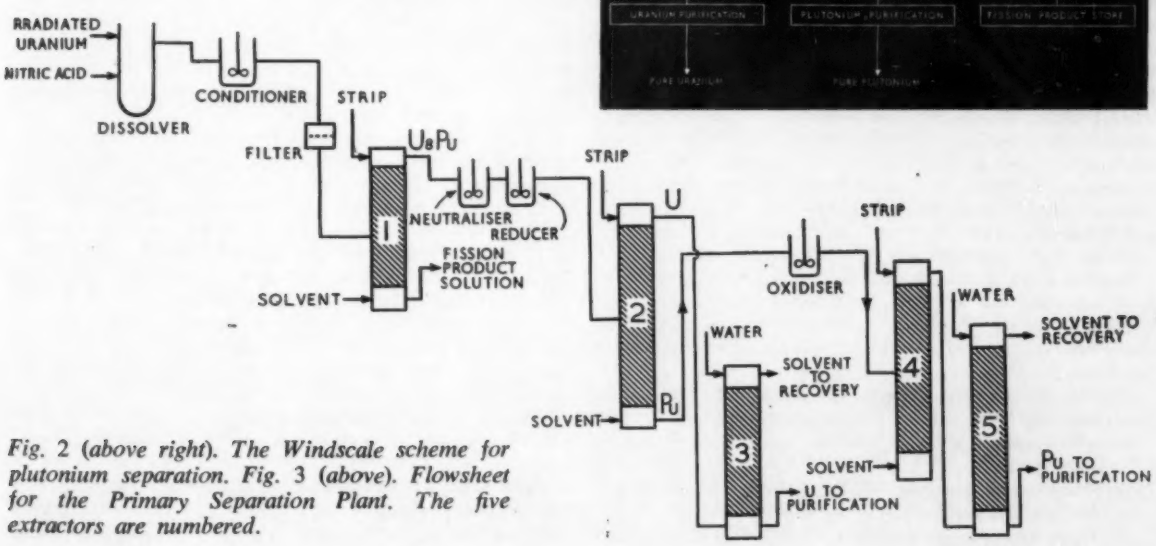




*Fig. 2 (above right). The Windscale scheme for plutonium separation. Fig. 3 (above). Flowsheet for the Primary Separation Plant. The five extractors are numbered.*

was the prospect that any plant breakdown, or any leak or choking due to sluding or precipitation might lead to the plant having to be abandoned. Thus any plant built for use with active materials must be operated remotely and have a reliable life without attention or maintenance.

A unique feature of fissile materials such as plutonium or U235 is that a chain reaction might be set up if more than a critical amount of the element accumulates in one place. If such a critical assembly were to be created by accident in the chemical plant, an explosion might result which, although small in magnitude, would be serious in its consequences, in that radioactive materials would be dispersed into the surrounding area. The critical amounts of fissile materials are small and are complicated by such factors as the physical form of the material, the presence of contaminating elements, and the geometry of the system. The design has to cater for this hazard and has to ensure that the control is sufficiently good to guarantee that plutonium cannot accumulate.

The toxicity of radioactive materials is such that the allowable escape into the working area is virtually nil, and a combination of plant containment and ventilation must ensure that this condition is met. Processes have to be carried out in vessels sealed from the working atmosphere, and vented via mist-precipitating and scrubbing systems to a high stack. Of necessity, these vessels are situated in an active cell which is unapproachable and this acts as a secondary protection. Pipes and instrument lines must pass through the shield wall, however, so the ventilation system is arranged that air passes from the operating area to the active cells to the stack. At all times the air velocity through the gaps in the shield wall must be sufficiently high to prevent back diffusion if there should be an accidental escape of activity inside an active cell.

The quantity of radioactive materials that can be allowed to pass into the effluent system is very low, so that stringent precautions are necessary to ensure that accidental escape is not possible. Cooling water condensates and wash-down waters must always be collected and tested for activity before disposal. All plant and vessels must be arranged so that leaking liquors will pass to collecting trays, and thence to tanks where they can be tested and returned if necessary to permanent store.

In conventional chemical plants the methods used for taking samples have little or no effect on the plant layout, but in an active plant the samples have to be taken in shielded containers by a system of remote operation. The inaccessibility of the plant during operation means that a system of *ad hoc* sampling cannot be devised. All sampling points must be arranged before the plant goes into operation, and as all samples are required to be withdrawn through the shield, careful positioning of plant is required so that this can be achieved. Thus sampling has to be treated as a special feature to be considered during the design study, while all the eventualities that may arise during commissioning and operation must be considered at the same stage. It is thus evident that the design and layout of a plant dealing with radioactive chemicals is substantially influenced by the new hazards which have been introduced.

In addition to the normal criteria and principles of design required by the chemical nature of the processes involved, the following demands have to be met:

(1) The plant must be placed behind a biological shield to protect the operator from radiation.
(2) All operations must be remotely controlled by means of instruments.
(3) Design and construction must ensure an adequate lifetime without attention or maintenance.
(4) There must be no possibility of escape of activity into the effluent systems or environment.
(5) The geometry and control of the plant must ensure that critical assemblies of plutonium cannot occur.
(6) Sampling facilities must be built-in to cater for all possible requirements.

## The Choice of Plant

The main advantage in the solvent extraction process lay in the fact that it was carried out entirely in the liquid phase and at ambient temperature. It was necessary, however, to carry out each stage of the process as a unit operation, separately controlled, so that extreme flexibility could be achieved and modifications introduced as they evolved in the development programme. The design conception included the five following points: the plant would be built within a cell with 3 ft. concrete walls; there would be complete containment of liquors, freedom from maintenance requirements, and no possibility of choked pipes; the plant would be operated from a control station outside the cell. The maintenance restriction means that all operational methods with a known risk of failure had to be eliminated. A complete guarantee of reliability was impossible, so it was necessary to duplicate equipment at critical points. The maintenance schedules of chemical plants handling nitric acid solutions were closely examined and a list made of those items requiring periodic attention. Pumps, valves, glands, flanged joints, lubricated bearings, mechanical moving parts, electrical contacts were all marked down as unsuitable. The design of the plant thus became a formidable undertaking and it was decided that as far as possible all operation should be continuous, and all liquid flows by gravity. The plant would be of stainless steel with all welded construction, with a standard of welding and inspection to guarantee soundness. Stainless steel (composition 18Cr/13Ni/1Nb) was used because of its increased resistance to corrosion. There would be no mechanical moving parts, requiring lubrication inside the shield. This meant that vessels requiring stirring had to be positioned with the stirrer shaft passing through the shield so that it could be driven by a motor in the operating area.

The following examples show how these principles were applied to the design of individual items of equipment.

(1) Dissolution of uranium is carried out by the addition of the uranium continuously to nitric acid boiling under reflux. The solution is displaced by fresh nitric which is added at a controlled rate. The corrosion conditions are severe, and available data showed that a thick-walled vessel would be required. There was doubt about the behaviour of welds so it was decided that there would be no welds under the liquid level. A tubular vessel was punched out of a solid ingot to the maximum diameter obtainable and this determined the size and shape of the finished dissolver. All pipes were introduced through the top except the overflow, which was given special attention with regard to workmanship and inspection.

(2) Flow control and measurement was achieved through a slowly rotating arm and bucket, which lifted fixed amounts into a tundish, the motor, reduction gear and controls being situated outside the shield.

(3) The choice of contactor lay between simple vertical columns, or a variety of the stirred counter-current mixer settler types. The difficulties introduced by a large number of stirrers and the problem of dealing with sludges and emulsions in the settler boxes were considered so formidable that vertical columns packed with Lessing rings were used.

(4) Tubular evaporators and concentrators were ruled out on reliability grounds, and simple pan-type evaporators adopted for use as required. Valves were eliminated and

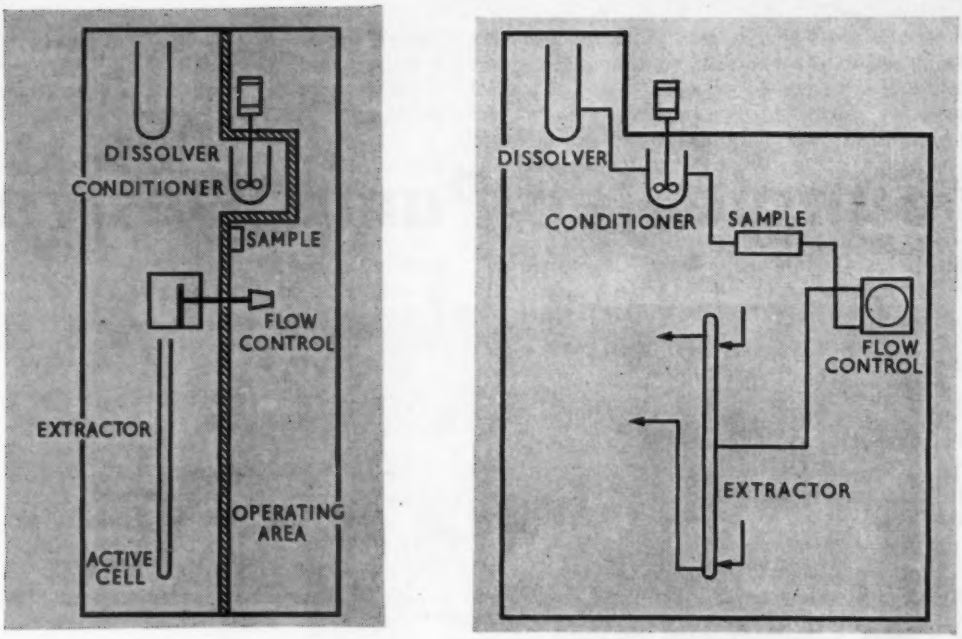



*Fig. 4. Plant arrangement in the Primary Separation Plant. Access to the plant is possible where required.*

vacuum systems sealed by a series of lutes up to 40 ft. high on occasion.

(5) As the operation was continuous, sampling was largely carried out from the streams flowing between the vessels. The pipes were led through the shield wall into subsidiary bulges containing shallow troughs which were used for sampling and instrument control. The small amount of liquid present eased the shielding problem and the samples were taken by remote operation using the "fountain pen filler" of rubber bulb and glass tube.

(6) The plant layout within the cell was so arranged that access to the plant was possible at each point where stirring, flow control or sampling was required. This led to a design where vessels and plant were hung on the cell wall, with occasional bulges to accommodate stirred vessels and sampling troughs. (See Fig. 4.)

## Control and Operation

The presence of radioactive elements seriously complicates control analyses, which cannot be carried out quickly in a simple plant laboratory. It was therefore necessary for control purposes to develop instruments giving quick and reliable results, and it was soon obvious that such instruments would require regular maintenance, otherwise they would lose their accuracy. Instrument control was thus effected in the subsidiary sampling bulges; the instruments are presented to the liquid flowing in the trough through a hole in the shield, and by the same route they can be removed for repair.

Continuously recording instruments were installed to log not only volumes, flow rates, temperature and pressures, but also the concentration of plutonium, uranium, fission products and nitric acid in the liquids flowing from the extractors. Alpha activity was determined by presenting a film of liquid to a scintillation counter; ion chambers or Geiger counters were used to measure the beta-gamma activity of liquid flowing in a shallow trough. Density was accurately observed by means of a stainless steel bob immersed in the liquid and suspended from a piece of soft iron situated in an electric field. Acidity control was by automatic titration of an aliquot with standard alkali using a conductiometric method and small constant flow pumps for volume control. All instrument readings were recorded and displayed at control stations situated at strategic points in the operating area. All inactive control valves and instruments were also arranged at these stations so that full control of each section of the plant could be effected from them.

The construction of the Primary Separation Plant was completed in late 1951, and a series of test runs of inactive solutions under stimulated processing conditions was made to check the design and to confirm the proposed operating techniques. Modifications shown to be necessary were then carried out and the plant after a trial run with trace activity was put into full operation. It has been operated successfully as a production unit since that date.

As experience was gained in the operation of the process, techniques were developed for washing and decontaminating plant, which reduced the radiation levels sufficiently to permit access behind the biological shield. Although the procedures are costly and time-consuming, they have made it possible to approach the plant and carry out modifications. The adoption of this pratcice of "planned entry" into active areas has also meant that occasional maintenance can be done on equipment providing that it can be easily cleaned by remote operation and suitably shielded during the repairs. As a result a much wider range of equipment can no bew used in active plant, while the need to provide duplicate equipment for insurance purposes is lessened. This has simplified many design problems and will considerably reduce the capital cost of future separation plants.

# Simple Jet Pump Design

by R. H. B. FORSTER

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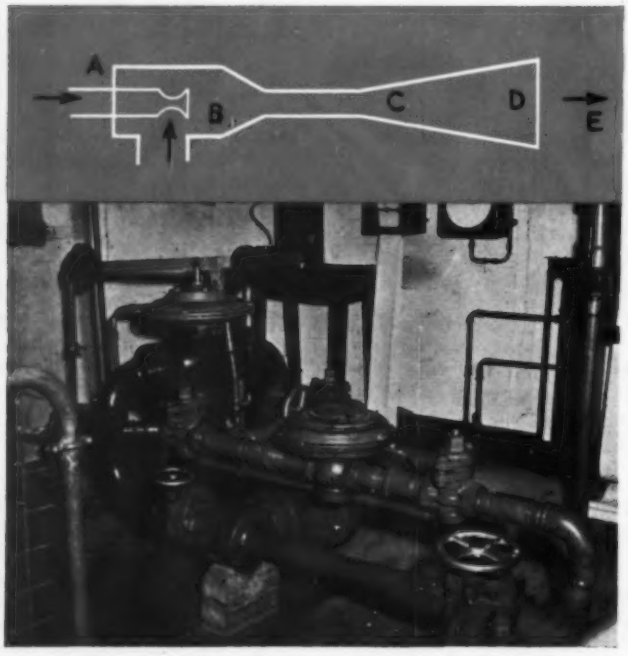



*Fig. 1 (top). The key features of a simple jet pump (schematic). Fig. 2 (left). A jet pump used to boost pressure in a gas main.*

THE Jet Pump is often referred to as an injector, or as an ejector, depending on its particular function. Although it is inherently an inefficient device, its simplicity, cheapness and reliability have created for it a wide field of uses. A simple form of the pump is shown diagrammatically in Fig. 1. A jet of fluid at high pressure is supplied from the pipe *A*. The fluid to be entrained enters at *B* and the mixture combines at *C*. Most of the velocity head at *C* is reconverted to pressure head in the diverging section *D* and the combined stream is carried away in the pipe *E*.

For best efficiency, the dimensions of the jet and the diameter and length of throat should be proportioned in accordance with the specific duty to be performed; any departure from these conditions may result in a substantial drop in efficiency. In many cases the design of a jet pump is a difficult matter which is best left to specialists. There are, however, certain applications which lend themselves to a simple solution, and at the end of this article a method developed by the author is discussed.

This type of pump is widely used for the following purposes: fume extraction; vacuum production; vacuum augmenting (vapour compression); thermo-compression; draught augmenting; gas boosting; sump drainage; chemical metering; and solid conveying.

*Fume Extraction.* The jet pump is often employed for the removal of corrosive fumes from fume cupboards or from processes generally. It lends itself readily to construction in acid-resisting material in those sections which will be subject to corrosion. As it is only the stationary portions of the system which come into contact with acid fumes, a blower of standard construction can be used to supply the air for pumping. The former consist of the ducts leading from the fume cupboard to the ejector; the air jet ejector itself and the ducting on the discharge side. The design of such a system is used later as an example of calculation.

*Vacuum Production.* There is a very wide field of use under this heading. Where the pump is used as an ejector to produce a vacuum by the removal of air or other incondensable gases, usually steam is used as the operating medium. A single stage ejector can be used effectively for vacuum up to 26 in. of mercury, but for the sake of economy in steam further stages are used. Fig. 3, shows the most suitable number of ejector stages for varying vacuum and steam pressure. These represent standard conditions and assume an adequate supply of cooling water at a temperature of 60-70° C. For speci-

fied conditions, it is possible to produce designs outside the range shown in Fig. 3; thus a single-stage ejector can be designed to produce up to 28 in. vacuum if necessary. A vacuum of very high order can be produced with a multi-stage ejector.

*Vacuum Augmenting.* Where it is necessary to extract large volumes of water under vacuum and where direct condensation is not possible, it is usual to employ a vacuum augmentor. This compresses the water vapour to such a pressure that it can readily be condensed with the available supply of cooling water or other cooling medium. Very large units of this type are often required and standard sizes with suction branches up to 30 in. diameter are made.

*Thermo-compressors.* Where a chemical process requires the evaporation of large quantities of water it is possible, by means of a thermo-compressor, to effect a substantial saving in steam. An ejector is used to reduce the pressure at the surface of the liquid to be evaporated and thereby lower the boiling temperature. The vapour which is evolved is then compressed by the ejector and is passed over the outside of tubes containing the liquor, where it can be condensed at a higher pressure and temperature than that of the liquor.

*Draught Augmenting.* This application is very similar to that of fume extraction. It may be that a furnace or boiler lacks draught and a permanent induced or forced draught installation is not justified. If an adequate supply of steam or compressed air is available an ejector can be used.

*Gas Boosting.* The use of high pressure gas mains has rendered it possible to employ some of this energy to step up the pressure in a low pressure main. Fig. 2, shows an installation using a jet pump to maintain a pressure around 4 in. water gauge in the main. The high pressure supply is at 2½ psig. When the pressure drops below 4 in. a governor opens and admits high-pressure gas to the injector and the outlet gas is boosted to 9 in.

*Chemical Metering.* A further application is in connection with supply of a metered quantity of liquid for a chemical process. For example, a jet of water may be used to elevate acid from a carboy. Providing the mixture is discharged at approximately the same level as that of the acid in the carboy, a constant strength of acid solution can be maintained. A valve in the line from the carboy to the jet pump can be preset to give the required strength. A motorised valve can be operated from a *p*H control to shut off the acid supply when the desired *p*H is reached.

*Solid Conveying.* For the pneumatic handling of solids, an ejector system forms a convenient alternative to the conventional suction blower and associated filters. The ejector can be used without filters, and in cases where the gases are too hot to be handled by a blower.

## Approximate Design Method

A simple method of design has been developed, and has been tried out in a variety of practical applications. This method ignores the thermodynamic effects occurring if an appreciable compression ratio is used. It is therefore restricted to instances where a liquid is employed which is virtually incompressible or to a gas where only a small degree of compression is created. Provided these conditions are observed, a good degree of accuracy can be obtained.

The over-all efficiency of an ejector can be considered as consisting of two parts:

(*a*) *Diffuser Efficiency.* The fluid which is entrained sustains certain frictional losses in passing through the ejector. These occur at entrances to the throat; in surface friction in the throat; and in the diffuser portion after the throat. These losses will depend on the design of the ejector, but for a good design the losses should not exceed 30% of the velocity head at the throat. This part of the efficiency, which is known as the diffuser efficiency, may therefore be taken for average conditions as equal to 70%.

(b) *Kinetic Efficiency.* The forcing jet on leaving the nozzle must be travelling at a higher speed than the combined stream in the throat; shock therefore occurs when the two streams meet. The kinetic efficiency can be expressed as the energy in the combined stream in the throat divided by the original energy in the forcing jet. If one considers the energy of the combined stream the maximum efficiency is 50%, but if one considers only the energy in the entrained fluid a maximum kinetic

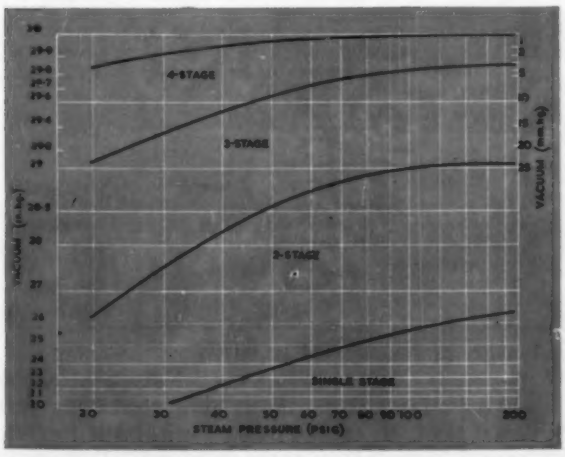



*Fig. 3. Characteristic curves of steam jet ejector.*

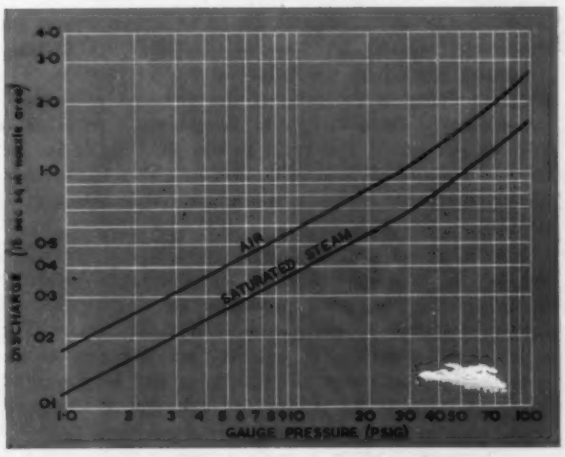



*Fig. 4. Discharge of air and steam through nozzles.*

efficiency of 25% is possible. The overall efficiency of the jet pump is the product of the kinetic and diffuser efficiencies.

To design a jet pump, it is necessary first to know the external pressure against which it will be required to operate; this is the sum of the suction and delivery heads. The quantity of fluid to be handled must also be known. If the total external pressure is not known it can easily be calculated by adding the friction losses in the piping to the static head which it maintains.

*The Injector Body.* It would be possible to make an injector operate against low heads by directing a high-speed jet against a circular hole in a plate. The efficiency would, however, be very low, and there are several factors that are important in improving the performance. These are as follows:

(i) *The Inlet.* This is shown at *B* in Fig. 1. The form of this varies considerably and it is not of such importance as some of the other features. It may take the form of a large radius leading direct to the throat; more usually it is coned as in Fig. 1.

(ii) *The Throat.* Ratios for length to diameter of the throat of up to 8:1 have been recommended by various writers. On the other hand, some standard injectors of high-efficiency are available with ratios much less than this. However, in these cases the inlet and outlet usually have a long and very gradual slope. In any case it appears to the writer that the most important dimension is that from the tip of the nozzle to the far end of the parallel portion and it is this dimension that should be of the order of 8 diameters or more.

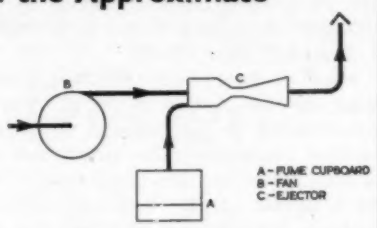
(iii) *Diffuser.* The velocity in the throat is usually high and it is necessary to convert the kinetic energy to pressure energy. If a sudden enlargement to a tank or large pipe line occurs at the end of the throat, most of the kinetic energy of the jet will be lost. It is usual, therefore, to provide a gradual taper in this portion. The highest efficiency occurs at an included angle of about 5 degrees but there is not a serious loss up to an angle of 15 degrees. This value should not be exceeded.

(iv) *The Forcing Nozzle.* For nozzles operating at low pressures, a simple circular orifice with a radiused inlet is adequate. For higher pressures it is necessary to use a convergent—divergent nozzle in order to obtain the maximum velocity. A standard textbook on thermodynamics should be consulted in this connection. The deciding factor is the ratio of the absolute pressure at the discharge from the jet to the absolute pressure at inlet to the jet. If this ratio is less than 0.528 for air or 0.54 for steam, it is advisable to use a convergent-divergent nozzle; if the ratio is above this figure a plain nozzle can be used.

Fig. 4, shows the discharge from a nozzle in lb./sec./sq. in. of nozzle area for various gauge pressures in lb./sq. in. A curve is shown for air and another for saturated steam. In each case discharge is assumed to atmospheric pressure. If however the pressure on the discharge side is lower, the discharge will be increased.

Fig. 5, shows the theoretical velocity of discharge from nozzles for plain and for convergent-divergent type. In each case, it is again assumed that the gas is expanded to atmospheric pressure.

## Example of the Approximate Method




*Fume Extraction* Supposing it is desired to maintain a speed of 3 ft./sec. through a fume cupboard door when the opening measures 2 ft. × 9 in. The volume of air will be $2 \times 0.75 \times 3$

$= 4.50$ cu. ft./sec.

Allow a velocity of 30 ft. per second in the ducts. Area of duct

$= \frac{4.5}{30}$ sq. ft.

$= 0.15$ sq. ft., or 5.3 in. diameter.

Allow 6 in. diameter.

Assuming there is 30 ft. of duct with 2 bends and a cowl. The dynamic head corresponding to 30 ft./sec. is $\left(\frac{V}{66.1}\right)^2$ for air at atmospheric pressure and temperature or in this case

$\left(\frac{30}{66.1}\right)^2 = 0{,}206$ in.w.g.

Entrance loss = 0.5 velocity heads

production of velocity head $= 1.0$

2 bends at 0.25 $= 0.5$

One cowl $= 1.5$

30 ft. of 6 in. $= \frac{4 \times 30 \times .01}{.5}$

$= 2.4$ Velocity heads.

Total $= 5.9$ velocity heads.

$= 5.9 \times .206$ in.

$= 1.22$ in.

For a diffuser efficiency of 70%

$$0.7 \left(\frac{V_t}{66.1}\right)^2 = 1.22$$

$V_t = 88$ ft./sec.

The optimum jet velocity $V_1$ will be twice this

i.e., 176 ft./sec.

and the jet pressure is 7.1 in. W.G.

Allow say 10 in. W.G. at the Fan. The quantity of air required at the fan under conditions of best efficiency is equal to the quantity induced, i.e., 4.5 cu. ft./sec. or 270 cu. ft./min. The fan specified should, therefore, have a capacity of about 300 cu. ft./min. against a pressure of 10 in. W.G. The area of the primary jet is obtained as follows: Assume an orifice coefficient of 0.8

The quantity passed $Q = 0.8\ A\ V_1$

where $A$ = area of jet

$$A = \frac{Q}{.8V_1}$$

$$= \frac{4.5}{.8} \times 176$$

$= 0.032$ sq ft.

$= 2.4$ in. diameter

The throat must carry 4.5 cu. ft./sec. of induced air plus the same volume of primary air, i.e., 9.0 cu. ft./sec. The velocity at the throat is 88 ft./sec.

$$\text{Area} = \frac{9.0}{88} = 0.102 \text{ sq. ft.}$$

$= 4.26$ in. diameter

## Design of the Injector Body

The basic principle is that the velocity head of the combined stream at the throat must exceed the total external head, $H$, against which the pump is required to operate. If the velocity in the throat is $V_t$, the velocity head of the combined stream is $V_t^2/2g$ where $g$ is the

acceleration due to gravity. The conditions for pumping may thus be written:

$$H = C\ V_t^2/2g$$

An approximate value of the efficiency $C$ can be obtained by assessing the losses which occur in the ejector, which may be conveniently expressed in terms of head of fluid.

If the injected fluid is at rest at the inlet, it requires to be accelerated to the throat velocity $V_t$. For a sharp edged inlet this loss would amount to about 0.5 $V_t^2/2g$, but with a well radiused or coned inlet the loss may not exceed 0.03 $V_t^2/2g$.

In addition there will be a surface frictional loss in the throat, equivalent to a head $h$, given by

$$h = 4f(V_t^2/2g)\ (L/d)$$

where $f$ is a frictional constant depending on the surface condition and $L/d$ is the length/diameter ratio of the throat. In calculating $L/d$, the length $L$ should include a proportion of the inlet and diffuser. Typical values are $L/d = 8.0$ and $f = 0.006$, which give $h = 0.192\ V_t^2/2g$.

In the diffuser the loss can be expressed as $K(V_t - V_5)^2/2g$, where $K$ is a constant depending on the divergent angle of the diffuser and $V_5$ is the velocity in the discharge pipe, which will not normally be greater than $0.25V_t$. In this case the diffuser loss is $0.52K$. $V_t^2/2g$. If there is no diffuser $K = 1$. For a diffuser with angle 10 degrees, which is close to normal practice, $K = 0.17$ and the diffuser loss is 0.09 $V_t^2/2g$.

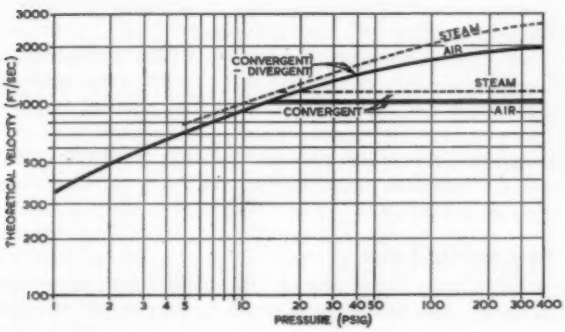



*Fig. 5 (above). The theoretical velocities of steam and air jets.*

The total loss is obtained by summing individual losses, which in the example given is $(0.03 + 0.19 + 0.09)$ $V_t^2/2g$ giving an overall efficiency of 69%. The original equation may thus be written $H = 0.69\ V_t^2/2g$. Thus, if the total head against which the pump must work is known, the throat velocity $V_t$ can be calculated. The momentum equation may then be used to determine the quantity of injection fluid required. This will give the total volume of fluid at the throat and will enable the throat diameter to be calculated:

$$M_1\ V_1 + M_2\ V_2 = (M_1 + M_2)\ V_t$$

where $M$ is the mass of primary injection fluid and $V_1$ is the velocity determined from Fig. 5.

If $V_2$ is equal to zero or is neglibly small we can write:

$$M_1\ V_1 = (M_1 + M_2)\ V_t$$

This equation enables the mass of injection fluid to be determined and the size of primary nozzle can be found from Fig. 4.

Fig. 6, has been evolved to facilitate the design of simple ejectors. It will be seen that air is used as the fluid for primary jet and induced stream. A density correction is required if any other fluid is used. If, for example, it is desired to exhaust 100 lb. of air per minute against a total pressure of 1 in. of water, the jet supply being at 20 psig, we proceed as follows: From the right hand portion of the figure follow a vertical line from 1 in. water up to the selected efficiency line, say 70%. From this point proceed horizontally to the left to meet a vertical line from 20 psig. These two lines intersect at about 13.7 mass ratio and the throat velocity is read off at 4,500 ft. min. The quantity of injection air is 100/13.7 or 7.3 lb./min. The total quantity of air at the throat = 107.3 lb./min. or 1,410 cu. ft./min. With a velocity at the throat of 4,500 ft./min. this throat area is 0.313 sq. ft. or 45 sq. in. (about 7½ in. dia.). The primary jet requires to pass 7.3 lb./min. or 0.122 lb./sec.

From Fig. 6, the quantity of air passed by one square inch at a pressure of 20 psig is 0.8 lb./sec. The jet area is 0.122/0.8 sq. in. = 0.152 sq. in.

*Acknowledgment is made to: Hick Hargreaves for permission to reproduce Fig. 2, and to Mr. J. T. Buist, of the South-Eastern Gas Board for details of gas pressure boosting systems and for the use of Fig. 3.*

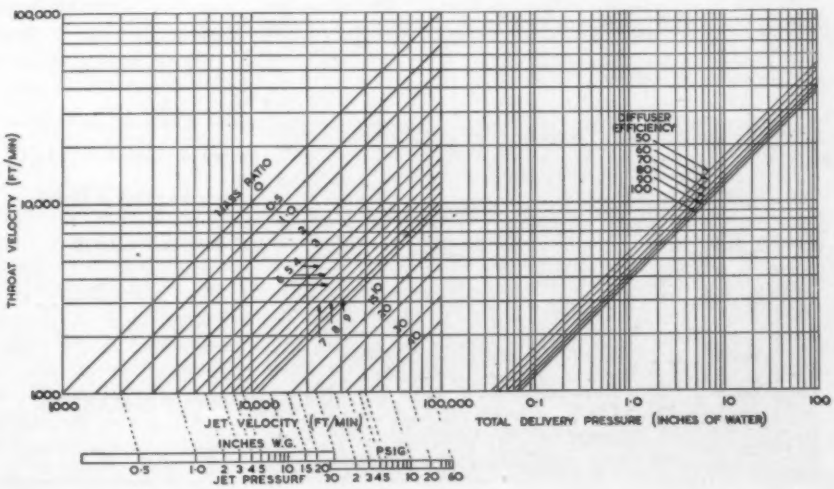



*Fig. 6. Chart for the design of simple ejector using air as pumping and pumped fluid.*

Viscosity measurements are commonly made in many industries. As a basis of process control viscometry can be expected to become increasingly important

# Potentialities of Viscosity

By W. BARKER*

IN this era of automatic process control it is surprising that so few control systems have been based on viscosity as the control variable. There is, for example, a wide field of potential application in synthetic resin manufacture.

In applied viscometry two main groups of substances are encountered, the so-called Newtonian and non-Newtonian materials. With the former, viscosity remains constant with temperature and is independent of flow-rate, with the latter viscosity is a function of flow-rate. Furthermore, Newtonian fluids have zero rigidity whereas non-Newtonian materials have finite values or their rigidity co-efficients. Fig. 1 summarises the characteristics of four different types of non-Newtonian materials encountered in viscometry, and shows how these compare with a Newtonian fluid.

Laboratory instruments, such as the orifice types (e.g. the Redwood, Saybolt and Engler viscometers), the capillary and falling sphere types, the bubble tube and the rotating cylinder types, are useful in their normal setting, but are not applicable to the continuous measurement of viscosity—an ability required of industrial instruments. In addition, the latter must often be able to function satisfactorily under conditions of elevated pressure and temperature.

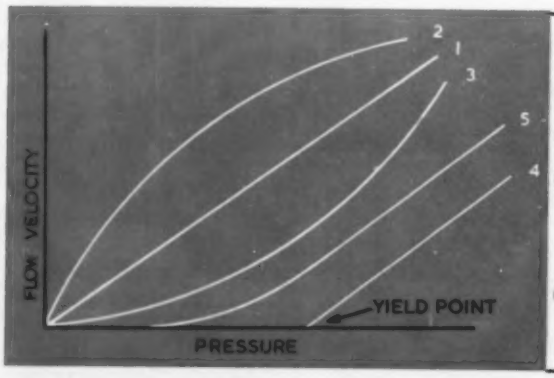
*The Norcross Viscosimeter* (Fig. 2) is a good example of this type, is designed to determine viscosity by measuring the time it requires a plummet to fall through a tube of the material under investigation. The plummet is enclosed in a long stainless steel tube which is fixed into the top of the processing vessel near the outer perimeter by flanged connections. The bottom of the tube must be immersed 12-14 in. in the material and the plummet completely submerged the total distance of its movement. The material being measured flows slowly through the holes in the side of the lower end of the tube so that the liquid in the well is representative of the batch at all times. A motor-driven cam raises the plummet and then releases it to fall through the material to the bottom of the tube. The time required for the plummet to fall through the material is recorded each three-minute period on a recorder dial graduated from zero to 100. Although the graduated scale does not record viscosity in poises, one of several plummets is selected having the required sensitivity to produce a record over about 80% of the scale.

This type of instrument has successfully been used to continuously record the viscosity of resin in reactors where it is essential to know when the resin has reached the pre-determined end point of polymerisation. No temperature compensation is possible with this type, and therefore control of the reactor temperature to $\pm 1^{\circ}$ F. is essential.

## Metering Tube

This is an interesting development of recent years designed for the control of the viscosity of varnish (Fig. 3). In this arrangement, liquid is supplied to the metering tube at a constant rate from a properly designed rotary pump. Pressure taps on each end of

* Elliott Brothers (London) Ltd.




| | |
|---|---|
| (1) NEWTONIAN FLUIDS | e.g. Glycerine, castor oil, mercury, water. |
| (2) DILATENT FLUIDS | e.g. Clay suspensions, silica slurries. |
| (3) THIXOTROPES | e.g. Printing ink, tomato ketchup, paper coatings. |
| (4) TRUE PLASTICS | The material exhibits no flow below a certain pressure (yield point). Above the yield point it behaves as a Newtonian fluid. |
| (5) PSEUDO-PLASTICS | Intermediate between a Newtonian fluid and a true plastic. |

# Control

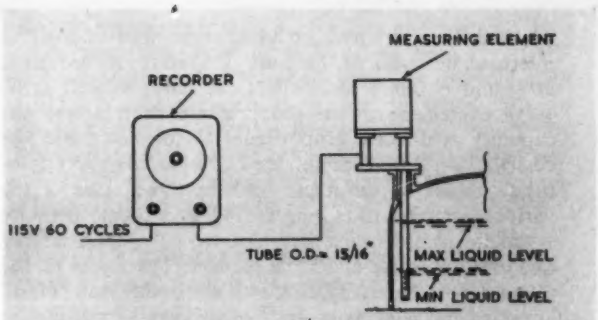



*Fig. 2. The Norcross Viscosimeter.*

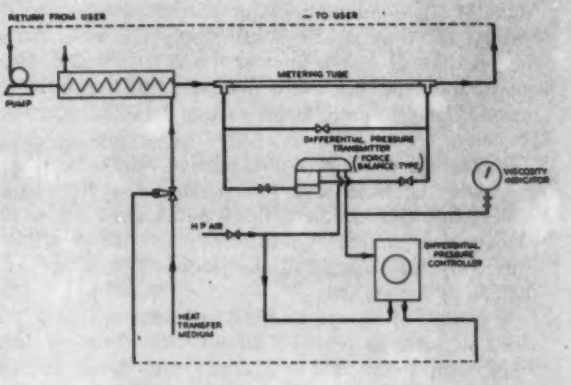



*Fig. 3. Metering tube for control of varnish viscosity.*

the metering tube are connected to a pneumatic differential pressure transmitter, which converts the differential pressure into an amplified air pressure of 3-15 psig. The system produces an air pressure which varies linearly with viscosity. If control is not desired, the output is taken to a pressure receiver suitably calibrated. When control is desired, the output is taken to a differential pressure controller, which actuates a valve, pump or other device to stabilise viscosity at the control point.

## Oil Viscometer

This is a novel viscometer using well-known hydraulic principles. It was primarily designed for automatic control of the viscosity of lubricating oils used in the forced lubrication systems of naval propulsion machinery. The design is based on work done by Admiralty scientists at Teddington, and has been developed by Elliott Bros. (London) Ltd. Although designed primarily for lubricating oil, there are obviously many other applications involving Newtonian fluids to which this viscometer would lend itself. Its principle of operation depends upon a number of well-known phenomena; firstly, when a liquid is forced through a capillary groove, the pressure drop is proportional to the kinematic viscosity provided the flow is constant; secondly, within the limits under consideration, the flow through a sharp edged orifice is only dependent on the upstream pressure head.

The operation of this viscometer (Fig. 4) is as follows. The liner *A*, with a helical capillary groove *B* machined in it, is contained in the main housing *C*, which is sealed off at one end by the small end cover *L*. The plunger *D* carries the jet arm *E*. The outlet of the jet arm is formed by the orifice plate *F*. Vertical downward thrust is provided by the helical spring *G* through the ball bearing *H*. The spring compression can be varied by means of the adjustment *J*. The jet arm is enclosed by the housing *K*, which is fitted with two circular perspex windows.

A continuous sample of oil is delivered under pressure (approx. 115 psig.) through port *N*. The oil flows to port *P* via the annular chamber *O* surrounding the plunger. The opening of port *P* is controlled by the position of the plunger, the lower land of which acts as a piston valve. The oil admitted through port *P* then flows through the capillary groove *B;* from there it passes up through the centre of the hollow plunger *D* and is finally discharged through orifice *F*.

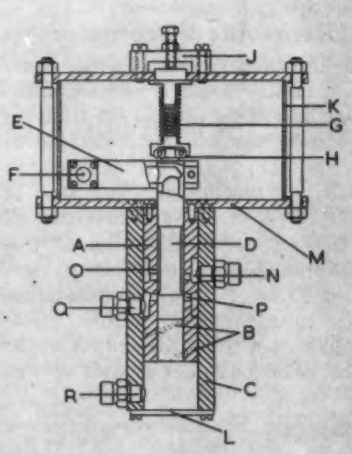



*Fig. 4. Viscometer design for control of lubricating oil viscosity.*

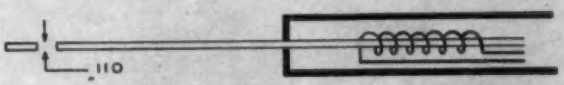



*Fig. 5. The sensing element of a Viscoson probe. Ultrasonic longitudinal vibrations are induced by the coil at the reed's resonant frequency of 28 kilocycles. The reed is pulsed each time its amplitude decays to 1/500th of initial pulse. Time for decay and rate of pulsing is thus a function of vicsosity.*

The oil then drains through a hole (not shown) in intermediate cover *M*. Pressure measurements are made at *Q* and *R* (entry and exit of capillary) as well as *N*.

As explained earlier, the pressure drop across the capillary is directly proportional to the kinematic viscosity if the flow is maintained constant. By an appropriate choice of variables—such as dimensions of the various components, spring setting, and supply pressure —the downward spring thrust balances the upward force due to oil pressure under the plunger. The forces on the plunger will be in equilibrium when the flow of oil admitted through port *P* by the lower land of the plunger equals the flow through the orifice. Since the pressure before the orifice remains virtually constant (there is slight fluctuation due to the vibration of the spring), the flow is also substantially constant. Hence, the pressure *Q* at the inlet to the capillary is a direct measure of the viscosity, since the difference in the pressure at *Q* and *R* is proportional to the kinematic viscosity.

Plunger *D*, which is a piston valve, would be subject to "hydraulic lock" due to unbalanced hydrodynamic forces, but this problem does not arise because the plunger rotates freely in the sleeve *A;* the rotation is caused by the reaction of the jet leaving the orifice at the end of the jet arm.

A feature of this particular viscometer is that it provides a hydraulic pressure output which bears a linear relationship to changes in viscosity, and therefore it can be used to actuate a control valve or other device which serves to vary the input of the controlling medium.

## The Ultrasonic Viscometer

This instrument measures the interaction of ultrasonic elastic waves with the fluid under observation. The system comprises a probe (which may vary in physical configuration), an electronic computer and a co-axial connecting cable. The standard computer contains a range-selector switch which permits a full scale reading of 50, 500, 5,000 or 50,000 centipoise × grams/cc. Electrical zero and calibration controls are provided for calibrating the probe computer combination to standard fluids of known temperature-viscosity characteristics. In addition, a variable output control is provided so that a full scale output up to 0-50 millivolts may be obtained for use with a standard electronic potentiometer recorder/controller. Full-scale accuracy of the system is ±2%.

Fig. 5 shows the principle of the probe assembly. It acts alternatively as a receiver and transmitter for ultrasonic energy. The sensing element proper is a 4-in. strip of magneto-strictive alloy 0.011 in. thick. The associated computer induces short pulses of current in the coil located within the probe barrel, causing the blade to vibrate at its natural frequency of 28 kc/s. There is virtually no motion at the geometric centre of the blade where it is joined to the diaphragm, and the maximum travel at the tip (2 in. from the diaphragm) is approximately 0.5 micron. The resultant alternating shearing action is in the longitudinal plane rather than at right-angles to the blade length. If an oscilloscope were connected to the terminals of the probe coil, a damped wave form would be observed each time a pulse was induced in the coil. This wave form would have diminishing peak amplitudes corresponding to the diminishing amplitudes of the mechanical vibration of the probe blade. When the amplitude decays to about 1/500th of the original value, the computer transmits another pulse to indicate another wave train. The repetition rate of these wave trains is about 50 per second in air and about 500 per second when the blade is in a fluid whose viscosity corresponds to the maximum of the computer range. As viscosity increases, the damped wave form increases in repetition frequency.

A block diagram of the basic Viscoson system is given in Fig. 6. The variable frequency generator pulses the probe circuit. The probe, the a.c. amplifier, the detector, the d.c. amplifier, and the indicator circuit comprises the receiving circuit. The signal is amplified and rectified in the a.c. amplifier, the detector removes the 28 kc/s component of the wave-form, and the d.c. amplifier controls the pulse generator. The indicator circuit responds to the average current delivered to it by the rectified and filtered wave-form.

Strictly speaking no viscometer is complete without temperature compensation, and here again the Viscoson scores. This compensation unit instantaneously and automatically corrects the measured viscosity so that the viscosity recorded and controlled corresponds to the desired reference temperature. The range of temperature variation on either side of the reference over which the compensation will accurately be affected is a

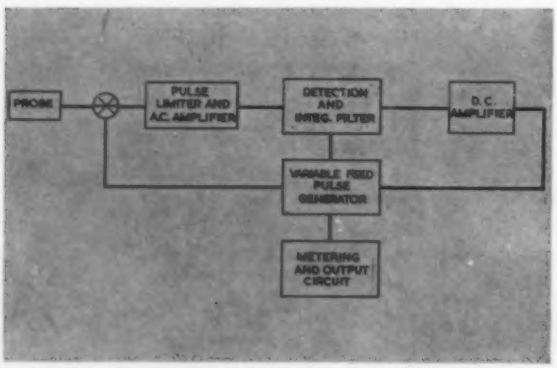



*Fig. 6. Block diagram of Viscoson system.*

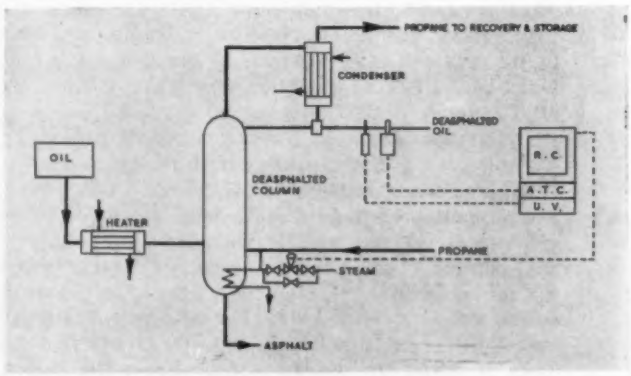



*Fig. 7. System for control of solvent refining.*

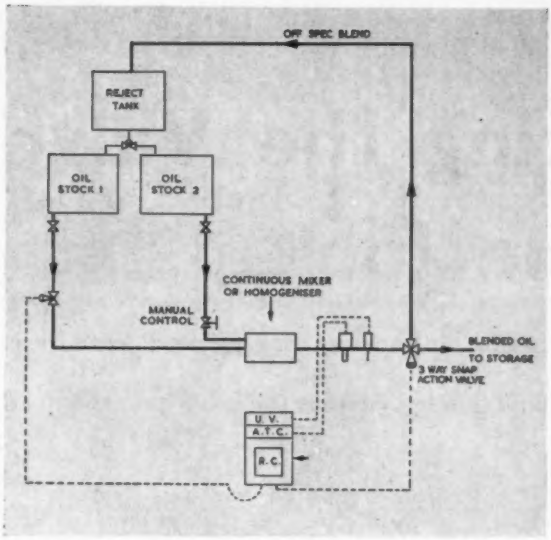



*Fig. 8. Control of oil blending.*

function of the characteristics of the product, the permissible error in compensation, and the reference temperature. For example, a particular mineral oil has a viscosity at 145° F. of 12 centipoises × grams/cc.; at this temperature the slope of the viscosity-temperature curve is such that the change in viscosity is about 5% per degree F. With a temperature variation of ±8° F. above the reference temperature of 140° F., the compensated viscosity recorded on the Viscoson changes less than ±1%. For a temperature swing of ±16° F., the corrected viscosity is within ±2%; for a temperature change of ±20° F., the recorded viscosity variation is less than ±3%. In the latter case, this is equivalent to holding the process temperature to ±0.6° F.

Three specific examples of the application of this instrument are now described.

*Oil Blending* (Fig. 8): In this arrangement two oils, stock 1 and 2, are blended in a mixer or homogeniser. In the line delivering oil 1 to the blending device there is a control valve, and in the line feeding oil 2 there is a manually operated control valve. The probe and resistance thermometer are fitted in the discharge line from the blending machine.

Controlling viscosity with the Viscoson is now firmly established in the U.S.A. and is rapidly "catching on" in this country. The special features, viz.—Hermetically sealed sensing elements, instantaneous response, and automatic temperature compensation, renders it particularly useful to the chemical and petroleum industries. In operation, the valve in stock 2 line is adjusted to give the required throughput. The control valve then takes over and provides the correct blend.

*Solvent Refining* (De-asphalting). Referring to Fig. 7 the charge is seen feeding via a heater into the de-asphalting tower. Since the viscosity of the de-asphalted oil can be used as a measure of the efficiency of the process, the Viscoson controller controls the heat input to the tower by measuring the viscosity of the de-asphalted oil as the end product, and automatically positioning the control valve to give the required heat to the tower and thus the required viscosity.

*Fuel Atomisation.* The efficiency of operation of fuel oil burner nozzles is dependent on the viscosity of the fuel. This can be controlled at an optimum value by controlling the flow of heat exchange fluid to the pre-heater, thereby regulating viscosity by continuously adjusting the temperature.

## The Advantages of Viscosity Control

As mentioned at the beginning of this article, viscometry has a promising future in connection with the control of processes for synthetic resin production. During the polymerisation stages of phenolic and alkyd resin manufacture, samples of batches being processed are taken and laboratory checked by out-moded and tedious methods. It is possible by the time the result of such a test is received by the plant operator for a batch to be off specification or even ruined.

A continuously reading viscometer would, therefore, solve the problem of labour spent on sampling and testing, and reduce product wastage. The Viscoson has an application here, since the polymerisation temperatures in many plastic manufacturing processes come within the operating temperature range of this instrument. Furthermore, since the Viscoson can form the basis of a control loop, polymerisation processes may be amenable to automatic control.

Another good example of saving labour and improving the quality of the end product, by the control of viscosity, is the bonding of abrasives to cloth. Viscosity of the adhesive has a pronounced effect on the weight of grain picked up, and therefore offers a good case for quality control. Although initially the adhesive is mixed to the correct viscosity in the kettle which supplies the "making machine," it will not, unless continuously corrected, remain at this viscosity. The reason is that, on the machine proper, the adhesive is stored in an open tank or trough. A rubber roll in contact with the base material revolves partially immersed in this adhesive open bath. The adhesive is continuously recirculated, flowing by gravity from the machine vat to a pump which returns it to the adhesive kettle. Over a period of time, diluent evaporates from the adhesive in the open bath and the viscosity of the solution increases. A change in adhesive quality results from the increase in viscosity, and therefore to maintain the correct grain weight of the finished product the viscosity of the adhesive must be kept constant.

Since the making machine runs at a high speed, spot checking of viscosity and periodic corrective measures were not satisfactory, as off-quality material could be produced with an accompanying financial loss. In this particular problem, the Viscoson was used together with a recorder/controller and proved highly satisfactory.

To conclude, therefore, control schemes, whatever the variable may be, are bound to pay off in the long run, whether this is by the saving of labour, keeping the product on specification, or in the saving of materials. Initial cost of instruments, whilst providing a deterrent to the timid, do not over-awe the manufacturer, who has learnt from experience that instruments are necessary for the successful and economic operation of his process.

# Selecting the Valve for the Job

Valve selection can be an onerous task as the literature is very scattered. This article provides the basic data required

**Table 1: Materials commonly used in Valve Manufacture and their applications**

| MATERIAL | TYPICAL APPLICATIONS |
|---|---|
| Carbon Steel | Chlorinated Solvents, Ammonia |
| Aluminium | Nitric Acid<br>Fruit Juices |
| Aluminium Bronze | Sulphuric Acid 50%<br>Hydrofluoric Acid<br>Organic Acids |
| Bronze | Dilute Organic Acids, Solvents<br>Dry Chlorine, Aldehydes, Esters |
| Phosphor Nickel Bronze | Caustic Solutions<br>Dilute Organic Acids |
| Inconel | Hot Gases, Organic Acids, Fruit Juices |
| Ni Resist | Caustic Soda Solutions, Dilute Sulphuric and Acetic Acids |
| Monel | Hydrofluoric Acid |
| Nickel | Caustic Soda<br>Phosphorus Oxychloride |
| Nickel Alloys<br>(a) Ni 63 Fe5 Mo. 30 | Sulphuric<br>Hydrochloric, Phosphoric Acids<br>Acid Chlorides<br>Alkaline Salts |
| (b) Ni 56 Fe5 Co15 Mo17 | Organic Acids<br>Oxidising Acid Mixtures<br>Dilute Hydrochloric Acid |
| (c) Ni 85 Cu 3 Si 10 | Boiling Sulphuric Acid (70-90%)<br>Hydrogen Sulphide |
| (d) Ni 56 Cu6 Cr 23 Mo 6 W 2 | Sulphuric Acid<br>Mixtures of Nitric and Phosphoric Acid<br>Caustic Solutions |
| Stainless Steel | |
| 18/8/1 Nb. | Nitric Acid, Solvents, Fruit Juices |
| 18/8/3 Mo. | Nitric Acid, Mixed Acids, Moist Chlorine Gas |
| Regulus Metal | Sulphuric Acid<br>Phosphorous Oxychloride |
| High Silicon Iron | Mineral Acids<br>Caustic Solutions |
| Chemical Stoneware | Mineral Acids<br>Wet Chlorine<br>Dilute Caustic Soda below 120° C. |
| Hard Rubber | Hydrochloric Acid 30% 40° C. |
| Soft Rubber | Hydrochloric Acid 30% 40° C. |
| Polytetrafluorethylene | Acids except Hydrofluoric, Caustic Solutions, Solvents |
| P.V.C. | Hydrochloric, Sulphuric, Hydrofluoric Acids (not above 60° C.)<br>Salt Solutions |
| Ebonite | Sulphuric Acid 50%<br>Hydrofluoric Acid 50%<br>Hydrogen Sulphide |
| Glass | Mineral Acids<br>Chlorine |
| Impregnated Graphite and Carbon | Halogen Acids<br>Hydrofluoric Acid (50%)<br>Hypochlorite Solutions<br>Ammonia |

VALVES are a small but important component of any chemical plant. The physical operation of a plant may be impaired if the valves connecting units do not function satisfactorily. Therefore, the procedure for selecting valves should be a logical one. It is with this in mind that the tables included with this article have been compiled. It is considered that valve practice in the field of steam handling and hydraulics is well established and, therefore, for the sake of brevity, has been omitted from the tables. Similarly, Reducing, Safety, Non-return and Special Control Valves have not been delat with in the text. The "Price Index" column is based upon the price of a 2-in. Flanged Cast-iron Plug Cock with the cost indices of the other types expressed as multiples of this price.

## Characteristics of Valves

*Cocks:* These are made in a variety of types in a wide range of materials and have a wide field of application. The cheaper bronze and cast-iron glandless varieties are not recommended for handling chemicals.

*Globe Valves:* To ease the task of classification, other types such as "Y" Valves, similar in their main constructional features, have been grouped together. The basic type is available in a number of modifications both as regards methods of seating and general construction. Seatings may be of the plug-type disc, composition or metal discs. The composition type are to be avoided for high temperature service where metal-to-metal seatings are preferred. Composition discs may also limit the application since, in some instances, they will be affected by the chemicals to be handled. Naturally the design of the valve will affect accessibility to the seatings when these have to be replaced or inspected. The Union or Bolted Bonnet type has advantages in this respect over the other types.

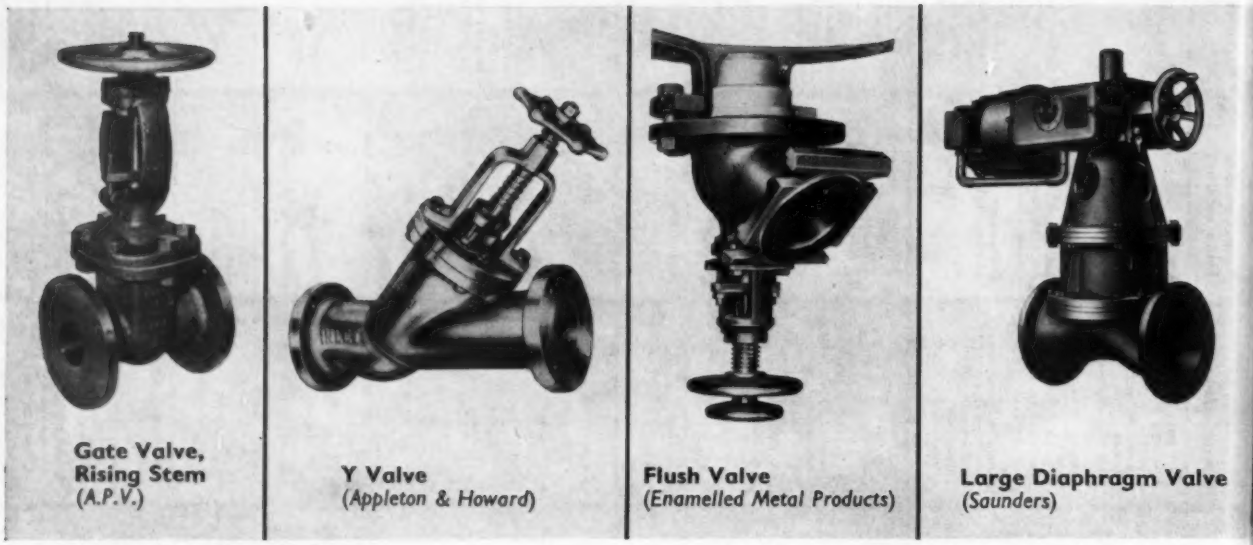
For vacuum duty, Globe Valves may be fitted with a bellows seal instead of the gland. Where it is especially important to avoid gland leakage, both the gland and the bellows may be used together. Occasionally, for high vacuum work, the gland may be of the Lantern Ring type fed with oil from a small container.

*Gate Valves:* This type has a number of mechanical variations which affect both the method of seating and

| *Type of Valve* | *Fluids Handled* | *Preferred Duty* | *Method of Operation* | *Working Conditions* | *Size Range (in inches)* | *Price Index* | *Materials of * Construction* | *Representative Manufacturers* | *Remarks* |
|---|---|---|---|---|---|---|---|---|---|
| PLUG COCKS | Liquids and Slurries | On-Off where frequent movement not required | Lever | 0-150° C.<br>0-200 psig.<br>0-70° C.<br>0-40 psig. | ¼-4<br>¼-6 | 1, 2.4<br>1.3-3 | *Cast Iron, Gunmetal*<br>Chemical Stoneware<br>Glass<br>Ebonite Silvertown<br>Ebonite | Crane<br>Hathernware<br>Q.V.F. | Armoured types available; also P.V.C. types |
| **GLAND COCKS** | Liquids and Slurriein | On-Off where frequent movement not required | Lever | 0-150° C.<br>0-200 psig. | ¼-4 | 1.1, 3.6<br>5.7 | *Cast Iron, Gunmetal*<br>Regulus Body, Bronze Plug | Vee Reg., Crane<br>Haughton, Appleton Howard | |
| **LUBRICATED PLUG COCKS** | Liquids, Slurries, Gases | On-Off | Lever<br>Compressed air motor | Vac. 0.01 in. Hg.<br>—20° C. to 200° C.<br>Pressure 6,000 psig.<br>0-120° C.<br>0-150 psig. | ¼-12<br>¼-6 | 2.3, 10<br>23<br>17<br>5.8 | *Cast Iron, Bronze*<br>Stainless Steel<br>*Cast Steel*<br>Chemical Stoneware | Audley Engineering Co.<br>Newman Hender Ltd.<br>Joshua Hindle<br>Hathenware | Stellite plugs and Ebonite bung available. |
| **ECCENTRIC COCK** | Viscous Slurries, Pulps, Liquids, Gases | On-Off | Lever | 0-250° C.<br>0-90° C. (where rubber parts)<br>0-125 psig. | 4-12 | 2.8 | *Cast Iron*<br>Acid-Resisting Bronze<br>Aluminium<br>Stainless Steel | Millspaugh Ltd. | Monel Seatings<br>Ni-Resist Plugs<br>Rubber Lining available<br>Vacuum requires modified stem seal |
| **GATE VALVES** | | | H/Wheel | 0-500° C.<br>0-600 psig | ¼, ½, 1, 1½, 2-10 | 8.1-9.5<br>2<br>6.5 | *Cast Iron*<br>*Cast Steel*<br>*Gunmetal* | Crane<br>Pegler<br>Blakeborough<br>Hopkinson | |
| | Liquids and Gases | On-Off | H/Wheel | 0-150° C.<br>0-250 psig. | ¼, 2, 2-12 | 13<br>—<br>—<br>— | Aluminium Bronze<br>Phosphor Nickel Bronze<br>Hastelloy Alloys<br>Monel Inconel Nickel | Langley Alloys | Double disc type preferred where maintenance difficult |
| | Liquids and Gases | On-Off | H/Wheel | 0-250° C.<br>0-250 psig.<br>0-150° C.<br>0-100 psig.<br>0-100° C.<br>0-50 psig. | 1½-12<br>2-48 | 13-15 | Stainless Steels<br>*Cast Iron*<br>,, ,, | A.P.V.<br>Langley Alloys<br>Blakeborough<br>Blakeborough | "Shovel" type available where gums deposit. Double Disc type for blast furnace and producer gas, blast type for pulps. |
| **LINE BLANKING VALVES** | Liquids, Gases, Suspensions | On-Off<br>Isolation of pipe-line sections | Lever<br>H/Wheel | 0-300° C.<br>0-1,500 psig. | 2-12 | 14-66 | *Cast Steel* | Joshua Hindle | Many types available |
| **GLOBE VALVES** | Liquids and Gases | On-Off and Throttling | H/Wheel | 0-150° C.<br>0-100 psig. | ¼-4 | 16.2 | Impervious Graphite | British Acheson | Do not use for oxidising conditions |
| | Liquids and Gases | Throttling. Hot fluids under pressure | H/Wheel | 0-500° C.<br>0-900 psig. | ¼, ½, ¾, 1 | | *Forged Steel* | Newman Hender<br>Vee Reg. | |
| | | | | 0-150° C.<br>0-150 psig. | 1, 1¼, 1½, 2 | 5<br>2.1 | *Gunmetal*<br>*Cast Iron* | Crane<br>Pegler | |
| **GLOBE—PACKLESS** | Liquids and Gases | On-Off<br>Throttling | H/Wheel | 0.0001 in. Hg.<br>0-200° C.<br>100 psig. | ¼-8 | 9<br>11 | *Cast Iron*<br>*Gunmetal* | General Engineering Co. | Can be used in systems using Mercury diffusion pumps |
| **NEEDLE VALVE** | Liquids and Gases | Throttling | H/Wheel | 0-300° C.<br>0-900 psig.<br>0-150° C.<br>0-200 psig. | ¼-2 | 6<br>9<br>25 | *Cast Iron*<br>*Gunmetal*<br>Hastelloys | Crane<br>British Ermeto<br>Langley Alloys | Bellows seal available for high vacuum |
| **Y VALVES** | Liquids, Slurries, Gases | On-Off | H/Wheel | 0-150° C.<br>0-200 psig.<br>(all metal valves only) | ¼-10 | 7.5<br>5.5<br>6.3-9.1<br>14.7<br>12.5<br>25-26<br>23-24 | *Gunmetal*<br>*Cast Iron*<br>*Regulus*<br>Stainless Steel<br>Aluminium Bronze<br>Hastelloys<br>Monel, Inconel<br>Nickel | Appleton & Howard<br>Joshua Hindle<br>Langley Alloys<br>Appleton & Howard | Rubber Linings available<br>Rod provided for clearing blockages |
| **FLUSH VALVES** | Liquids, Slurries | Vessel drainage and discharge | H/Wheel | 0-120° C.<br>0-150 psig.<br>0-150° C.<br>0-200 psig. | ¼-4<br>1-4 | 28.2<br>31<br>20<br>7.5<br>23.5<br>24<br>16.2, 27 | Chemical Stoneware<br>Glass-lined Cast Iron<br>Stainless Steel<br>*Gunmetal*<br>Monel<br>Nickel<br>AL & PN Bronze<br>Hastelloys | Hathernware<br>Enamelled Metal Pdts.<br>A.P.V., Langley Alloys,<br>Appleton & Howard<br>Appleton & Howard<br>Langley Alloys | Supplied in armoured types |
| **PISTON VALVES** | Liquids, Gases | On-Off and Throttling | H/Wheel | 0-450° C.<br>0-400 psig. | ¼-6 | 7, 9.5<br>11 | C.I., Bronze, Cast Steel | Klinger | Streamlined types available for slurries. Gland seal for vacuum. |
| **DIAPHRAGM VALVE** | Liquids, Slurries and Gases | On-Off | H/Wheel motor | 0.0001 in. Hg.<br>60-100° C.<br>250 psig. | ¼-14<br>1-6 | 6.5 | *Cast Iron*<br>Aluminium Alloy<br>Stoneware body | Saunders<br>Wynn<br>Edwards<br>Hathernware | Diaphragm material limits temperature |
| **PINCH VALVE** | Liquids, Slurries, Solvents and Gases | On-Off | H/Wheel | 0-120° C.<br>0-50 psig. | ½, ¾, 1, 1½<br>2-8 | 5.2 | Aluminium body or Cast Iron<br>Abrasion-resisting rubber synthetic sleeves | Wilkinson Rubber Linatex | Not above 120° C. in presence of strong oxidising agents |

* *Italics indicates valves not specifically designed for corrosion resistance.*

**Table II: List of valves available for use in the Chemical Industry**



**Gate Valve, Rising Stem** (*A.P.V.*)

**Y Valve** (*Appleton & Howard*)

**Flush Valve** (*Enamelled Metal Products*)

**Large Diaphragm Valve** (*Saunders*)

*Selection of some typical valves*

operation. Seating methods are Wedge Disc, Double Disc with either parallel or taper seatings; operation may be either by Inside Screw, Rising Stem or Outside Screw and Yoke.

The Wedge types are occasionally used where the fluids to be handled are likely to leave sticky deposits behind them. Some engineers like to use the Wedge type when the valve is installed with the stem downwards.

Double Discs are preferred where the presence of small amounts of grit is expected, for although one disc may become inoperative through grit on the seating, the other may still seat.

Of the methods of operation, the Rising Stem type is preferred when it is necessary to tell at a glance whether a valve is open or closed. A further advantage of this type is that the screw threads on the spindle are out of contact of the fluids being handled and, therefore, are not subject to corrosive influences. The Rising Stem type, however, is not considered to give such a tight seal at the stuffing box as the inside screw type.

*Piston Valves:* Certain types are suitable for chemical service, depending upon the materials of construction; this is particularly true of the type employing non-metallic sealing rings. Special streamline "Y" types are available giving a clear passage through the valve. For vacuum duty the normal gland is replaced by a Lantern Ring Packing sealed by oil.

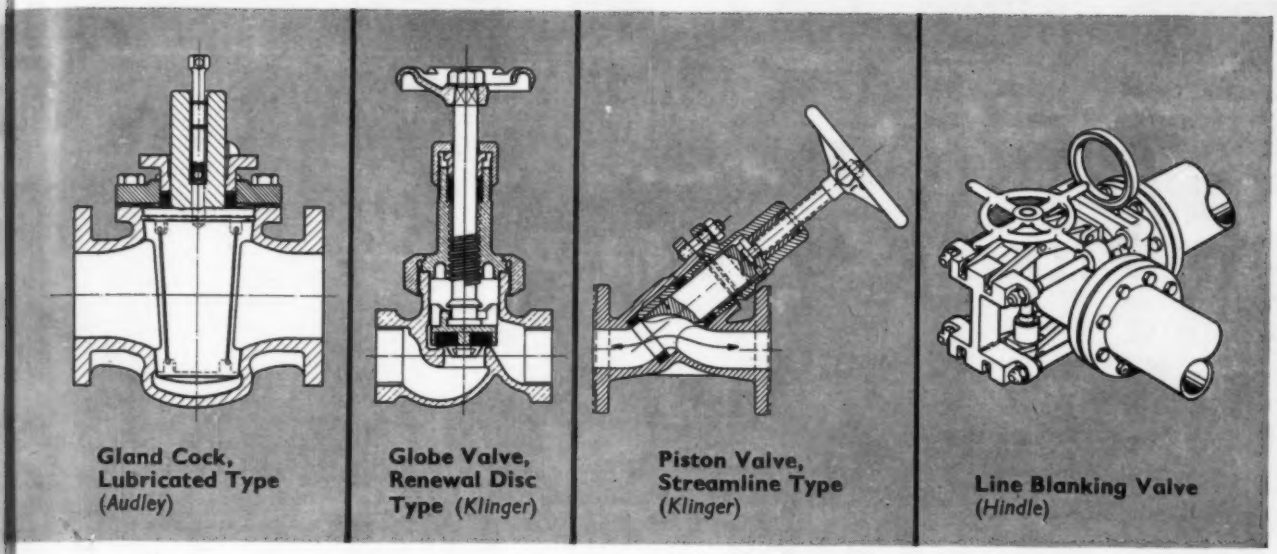
*Diaphragm Valves:* This type is very widely used, the main limitation being the diaphragm material. The development of diaphragms in P.T.F.E. (Fluon) and P.C.T.F.E. (Kel. F) has extended the range of materials which this type can handle and has raised the upper temperature limit. The type is available in a number of models, such as the straight-through and angle, and with different operating arrangements. In the large sizes, special sealed bonnets are necessary for high vacuum work. This latter type requires the bonnet to be connected to a rough vacuum.

*Line Blanking Valves:* Gate and other types used for off-service may develop leaks through various causes, particularly where severe temperature conditions are met. In such cases it may be advisable to isolate one part of a line system from another by bolting the blank end of a spectacle plate between adjacent flanges in the pipeline. This is a practice with many disadvantages—it may be messy, hazardous and laborious. To prevent this, special Line Blanking Valves have been developed employing the spectacle plate principle capable of giving reliable dead-tight shut-off. These valves have the advantages of absence of pockets and glands.

*Pinch Valves:* This is a very useful type, the limitations of which lie mainly in the sleeve material. Their method of construction does not lend them to high pressure applications.

## First Step to be Taken

The first step to be taken in settling a valve for a given use depends upon a number of factors. In cases where quick delivery is the main consideration, important technical points may have to be disregarded temporarily. Again, where the fluid to be handled is likely to attack ordinary constructional materials such as cast iron and red brass, the most important factor in choosing a valve, apart from the type of valve itself, may then be its material or materials of construction. In general, a combination of corrosion resistant and mechanical properties are demanded. On one hand it is essential that the materials used should have adequate tensile strength and shock resistance, otherwise valve breakage may occur. In selecting materials, variations in mechanical properties with temperature must be recognised. For example, carbon steel, mechanically strong at normal temperatures, is brittle at below 0° C. Seating materials must not be prone to galling when their contact surfaces slide over each other. On the other hand, the valve materials selected must resist satisfactorily the corrosive action of the chemicals they are to handle. It is as well to indicate here that the perform-



**Gland Cock, Lubricated Type** (*Audley*)

**Globe Valve, Renewal Disc Type** (*Klinger*)

**Piston Valve, Streamline Type** (*Klinger*)

**Line Blanking Valve** (*Hindle*)

*as used in the chemical industry*

ance of a material used for large equipment handling a given chemical or combination of chemicals, is not a criterion for selection of this same material for valve construction. This is because rates of corrosion tolerable with vessels would be sufficient to render a valve useless in a short space of time.

Where a common chemical known to contain impurities is to be handled, selection on the basis of the corrosive properties of the pure chemical alone is speculative, for the corrosive effect of the substance, plus impurities, may be altogether different from that of the pure material. Generally, the rate of corrosion will be greater, frequently where impurities are oxidising. Much less frequently does the presence of the impurity inhibit corrosion. Furthermore, the possibility of electrolytic action must not be overlooked. Another cause of wear is erosion, which occurs when the fluid to handled contains abrasive solids or where velocity through the valve is high.

Finally, where a gland is used, gland packing materials require attention. A wide range of packing materials in various forms are available for different services, e.g. for handling 50% sulphuric acid a woven blue asbestos packing is satisfactory, but for a more concentrated acid a similar packing treated with P.T.F.E. emulsion would be used. Packing rings of P.T.F.E. are also available for use in valves handling hydrofluoric acid.

In cases where purity of the handled chemical is the prime consideration, the choice of materials may be limited to the best—which may mean the most expensive—materials available. This may be the case in food, pharmaceutical and antibiotic manufacture. When, however, contamination is not the main issue, it may be more economic to use a valve of less resistant and of cheaper material and replace more frequently.

## Other Points to be Considered

Once the best materials have been decided upon a number of points have to be settled concerning the use to which the valve is to be put: (a) Condition of fluid being handled, i.e., are solids present? (b) Throttling or "On-Off" use. (c) Tightness of "Shut-off" required. (d) Frequency of operation. (e) Pressure and temperature. (f) Importance of avoidance of leakage at spindle.

Presence of solids eliminates such types as Gate, Globe and Needle from the field of choice. Slurries may be satisfactorily handled by Diaphragm, Pinch and "Y" varieties, also by Gland and Lubricated Plug Cocks.

Where flow control is desired, Globe, Piston, "Y" or Needle types are suitable. Where solids are present, "Y", Diaphragm or Pinch Valves or Lubricated Plug Cocks may be used. In the case of the Diaphragm or Pinch types either the Diaphragm or the Pinch Sleeve materials will limit the application.

Suitable types for "ON-OFF" operation are Gate, "Y", Gland and Lubricated Plug Cocks, and Pinch and Diaphragm Valves. Good quality Gland Cocks, particularly the Lubricated variety, have been used satisfactorily where the operation is frequent.

Where tight shut-off is required, Gate, Piston, Diaphragm, Pinch types and Gland Cocks may be satisfactory. However, caution is required with Gland Cocks as slight corrosion or wear on the plug will cause them to pass. Where absolute certainty of tightness is required then a Line Blanking Valve should be considered.

For high vacuum duty, the suitable choice must have an efficient method of sealing the operating spindle. Types employing metallic bellows are widely used for this purpose. Moreover, when used for those applications where high temperature as well as high vacuum are involved, they have an advantage over Diaphragm Valves which are also widely used for vacuum work. For moderate vacuum duty, Lubricated Gland Cocks may be used—as will most well constructed valves of other types, particularly those fitted with modified glands.

# A New Approach to Mixing Operations

Mixing is a difficult subject to treat theoretically: mixing of solids particularly so, because of the complicated manner in which flow occurs in powdered and granular materials. This article deals with the factors important in the mixing operation and explains how they may be applied in a commonsense way to practical problems.

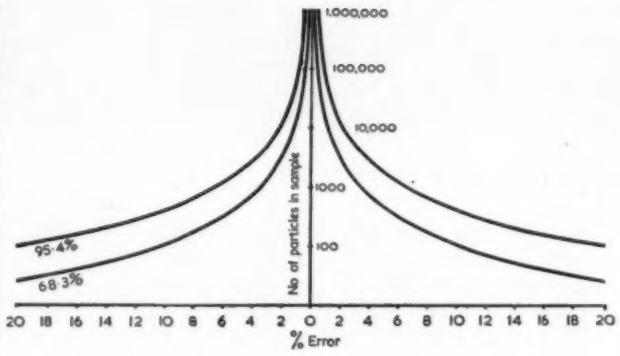



*Fig. 1. Sample accuracy increases with the number of particles it contains.*

THE mixing of solids is a widely practised operation in the chemical industry. It is to be found in such industries as cement and fertiliser manufacture at one end of the scale and in paint, insecticides and pharmaceutical manufacture at the other. It is an operation frequently encountered in other process industries such as food, cosmetics and packing manufacture.

In approaching a mixing problem the following series of steps may have to be taken:

(1) decide how well the components of a mixture have to be mixed.

(2) decide on the type of mixing required to give a desired final result from the properties of the materials to be mixed.

(3) decide whether tests are required in order to select the most suitable type of mixer available.

(4) once having decided upon a mixer, the most economical mixing procedure will have to be determined.

The size of the batch to be mixed may vary from a few pounds to tons while the proportion of the minor ingredient may be only a fraction of 1% or as large as 50%. The ingredients may have similar physical form, or they may be quite dissimilar; they may be powders made up of sub-microscopic particles, or granules of considerable size. The particles may tend to segregate, or to cling together in clusters, or to react chemically with one another or with the air.

In view of the wide diversity of problems encountered it is wise to examine each case individually on its merits. Consider, for example, the case of a pharmaceutical manufacturer producing pills containing 5 grains of drug dispersed in an inert extender. The purpose of the extender is to produce a pill of reasonable size. The pills could be made individually by weighing 5 grains of drug and the appropriate amount of extender, but this would be a grossly uneconomic business. Instead, a batch sufficient to make thousands of pills is prepared with the appropriate proportions of drug and extender. The batch is mixed and the pills are made from the mixture.

The requirements of mixing are that each pill shall contain, within a prescribed degree of accuracy, 5 grains of the drug. Provided that this condition is fulfilled it is a matter of indifference how the drug is distributed within the pill: we do not look at the product more closely than the individual pill. The scale set by the volume of the pill is termed the "scale of scrutiny".

In all mixing problems the concept of the scale of scrutiny is of great importance. It must be determined in each case by careful consideration of the use which is to be made of the product. The manufacturers of a certain rat killer incorporate a small percentage of poison, Warfarin, in oatmeal. The purpose of the product is to poison rats, so the scale of scrutiny is related to the size of a rat's mouth. The dispersion must be sufficiently good to ensure that each mouthful contains its quota of poison.

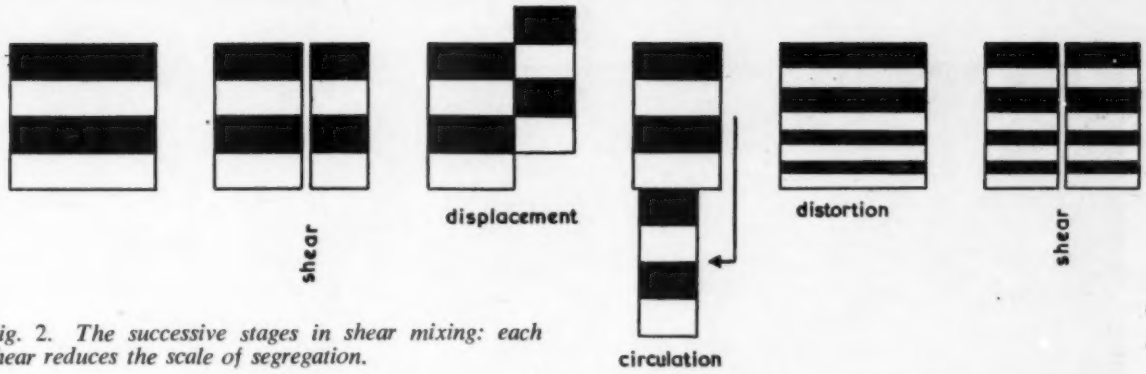



*Fig. 2. The successive stages in shear mixing: each shear reduces the scale of segregation.*

In some cases the scale of scrutiny is quite large. For example, if a mixture of two crystalline substances is sold in drums for subsequent dissolution in water, the scale of scrutiny is equal to the amount dissolved in water at one time. If, as may well be the case, the amount used at one time is never less than a drum, then the scale of scrutiny is equal to the size of the drum. Very large scales of scrutiny are rarely met in practice: in such cases it is usually more convenient and cheaper to measure the ingredients for individual packages rather than to mix a very large batch.

Often, the scale of scrutiny is very small. In the food industry self-raising ingredients are incorporated with flour, which is subsequently used to make cakes and similar foodstuffs. The texture of the cakes depends on the distribution of the raising ingredients: if the distribution is coarse, the texture is open with large holes. The scale of scrutiny is of the order of size of an air hole in a good fine textured cake—perhaps 2 mm cube. In the cosmetics industry it may be even smaller.

When the scale of scrutiny is reasonably large, samples of about the same size can be removed from a mix in order to assess whether a sufficient degree of mixing has been achieved. Where the scale of scrutiny is very small, larger samples have to be used together with tests to assess product quality. Methods of analysing the results obtained from samples are discussed later.

## The Best Possible Mixture

However well the mixing operation is performed, it is not possible to say that every sample of a given size will contain the same exact proportion of ingredients. This uncertainty arises because mixing is a chance process, like tossing a coin or throwing dice. When a coin is tossed, it is as likely to come down heads as tails. If the coin is tossed a hundred times, it is probable that on about fifty occasions it will show heads; but there is a small yet finite chance that heads will appear on all hundred throws.

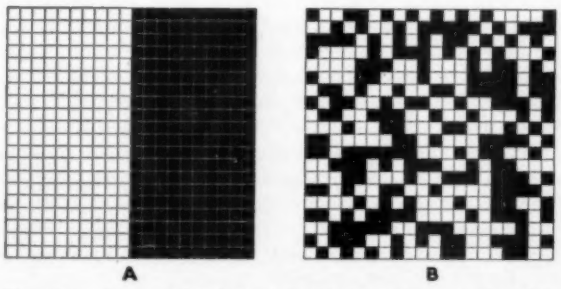



*Fig. 3. An artificial "mixture" of black and white squares: (a) completely segregated; (b) random mix.*

In a fifty-fifty mixture of particles of $A$ and $B$, a situation comparable with coin tossing exists. If the mixture is as intimate and uniform as it can be made, then there is an equal chance that the particle nearest to a particular point in the mixture is of $A$ as of $B$. Considering a sample of 100 particles, it is likely that about fifty of them are of $A$: but there is a small yet finite chance that all 100 are of $A$. The probability that a sample of $n$ particles will contain $r$ particles of constituent $A$ is given by the $r$ th term of the binomial expansion $(p+q)^n$ where $p$ is the proportion of $A$ in the mix and $q=1-p$ is the proportion of $B$.

$$\text{Probability of } r \text{ particles of } A = \frac{n!}{r!\ (n-r)!}\, p^r\ (1-p)^{n-r}$$

However carefully a mixture may be prepared, the majority of samples will not contain the theoretical proportion of ingredients. An idea of the magnitude of these errors is given mathematically by the standard deviation $\sigma=\sqrt{(npq)}$ for values of $p$ near $\frac{1}{2}$. In 68% of all samples, the actual number of particles of $A$ will lie within $\sigma$ of the desired number. In 99.4% the actual number will be within $2\sigma$ and in 99.7% within $3\sigma$.

In a perfect fifty-fifty mixture of $A$ and $B$, a sample of $n$ particles will contain on average $n/2$ particles of $A$. The standard deviation expressed as a percentage of the average number of particles of $A=\sqrt{(npq)}/\frac{1}{2}n \times 100=100/\sqrt{n}$. Thus, roughly two-thirds of samples containing 100 particles will be within 10% of the desired proportion of $A$, and this is the best possible accuracy which can be obtained by mixing the ingredients. For samples with larger numbers of particles, the accuracy is greater: two-thirds of all samples containing a million particles will be within 0·1% of the desired proportion of $A$ and 99·7% will be within 0·3%. The way in which the error varies with the number of particles in the sample is shown in Fig. 1.

This unavoidable error is of importance wherever the number of particles within the scale of scrutiny is small; for example, where the scale of scrutiny is itself small, or where the particles to be mixed are large. If higher accuracy is required with a given scale of scrutiny, the particle size must be reduced.

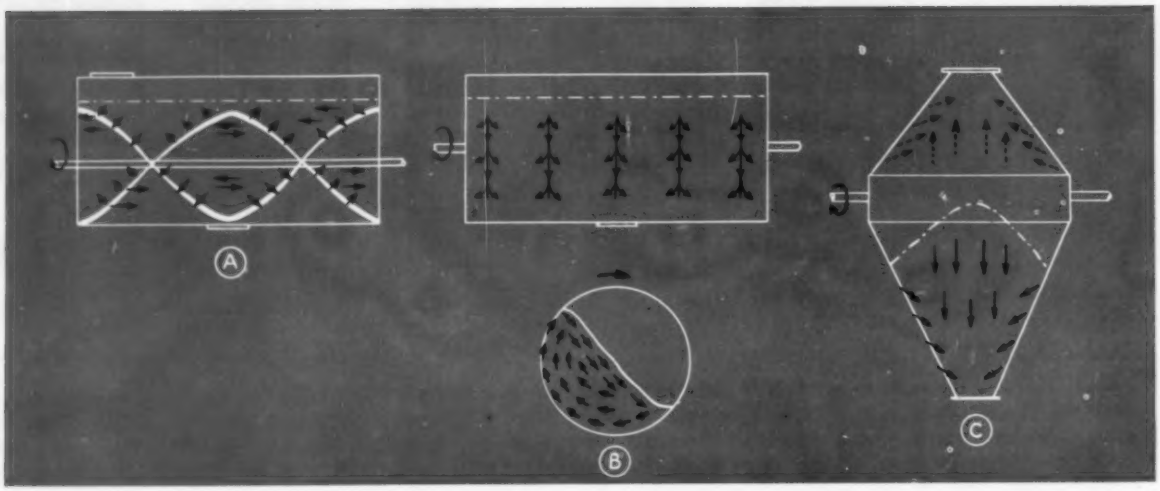



*Fig. 4. Three common types of mixer: (A) trough mixer in which the batch is sheared and circulated by the action of helical blades; (B) drum mixer in which shear is the result of slip in the charge; (C) double cone mixer in which charge falls from one cone to the other.*

## Mechanism of Mixing

It is difficult to achieve a perfect or random mixture in practice. To do so would involve a mechanism whereby the final position of any particle in the batch was purely a matter of chance. An artificial random "mixture" can be constructed from tables of random numbers. Fig. 3b gives an idea of how such a mixture looks. To obtain a dispersion of this kind involves bodily movement of the particles from the initial state, shown diagrammatically in Fig. 3a. Clearly, these movements must be on a scale at least as large as the volume of the batch.

Mixing must therefore take place in two operations: a large scale movement which transports regions of the batch in bulk and a small scale movement whereby individual particles exchange positions. The former process can be ascribed to shearing and transport within the batch. In the case of a dough, for example, it is the only form of mixing which takes place. The way in which the scale of segregation is reduced by shearing is shown in Fig. 2. After the batch has been sheared the two parts move relative to one another and are also subject to distortion. The scale of segregation (the size of the individual regions) is successively reduced by each shearing movement. In a well designed mixer the whole of the batch passes through a cycle of shearing, displacement and distortion at fixed or statistically distributed time intervals. In dough-like materials, shearing is brought about by moving paddles or blades of one kind or another. In powdered or granular materials shearing also takes place wherever flow occurs by a process of internal slipping. Slip is brought about by forces acting on part of the mix, such as, for example, gravitational forces in tumbling mixers or the effects of frictional drag of the walls in other types of mixer.

The small scale movement of individual particles may be compared with molecular diffusion in liquids and gases. In a tightly packed powder, particles are unable to exchange places. If, however, there is one hole unoccupied, then they may change positions by moving in turn into the hole. The rate at which the particles change places depends on the number of vacant holes. If the particles are completely separated, then the rate of interchange of position can be larger still. In this case, the mean free path, or average distance a particle can move before colliding with another becomes important.

In terms of the batch itself, the effectiveness of interchange and the scale over which it takes place depend on the density defect or degree of fluidisation. The speed of interchange also depends on the kinetic energy acquired by the particles in the region. This kinetic energy is only valuable in promoting diffusive mixing if it is of a disordered kind: if all the particles have identical velocity and direction, no mixing will take place. Thus, the best possible diffusive mixing will occur where considerable volumes of the batch are fluidised and in a highly turbulent condition. An important factor in the operation of a mixer is the order of size of these volumes over which individual particles are able to migrate: this may be called the scale of diffusion.

To achieve random mixing the process of shearing must proceed until the scale of segregation is smaller than the scale of diffusion. If it is stopped at an earlier stage, then aggregates of particles of the same kind are bound to exist in the mixture. On the other hand, if the scale of scrutiny is large compared with the particle size, diffusive mixing is relatively unimportant. All that need be done is to reduce the scale of segregation below the scale of scrutiny. Thus, the choice of mixer used depends in part on the scale of scrutiny of the final mixture. Where the scale of scrutiny contains few particles —because it is itself small or the particles are large—diffusive mixing is necessary and, therefore, a mixer should be chosen giving the largest possible scale of diffusion. Where the scale of scrutiny is large, containing many particles, mixing by shearing is the more important.

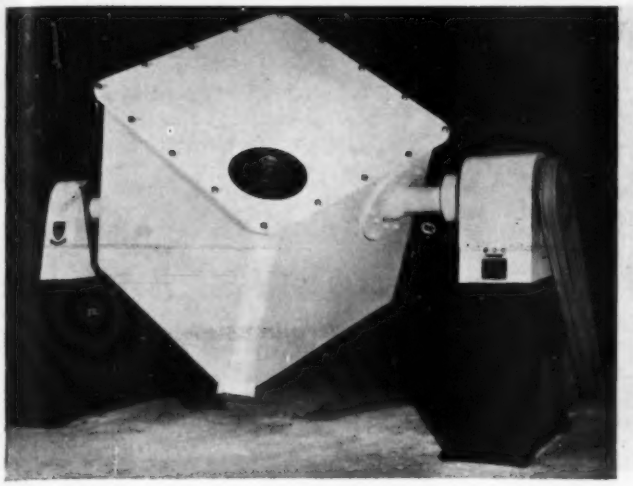


*Fig. 5. The rotating cube mixer—a modification of the double cone machine.*

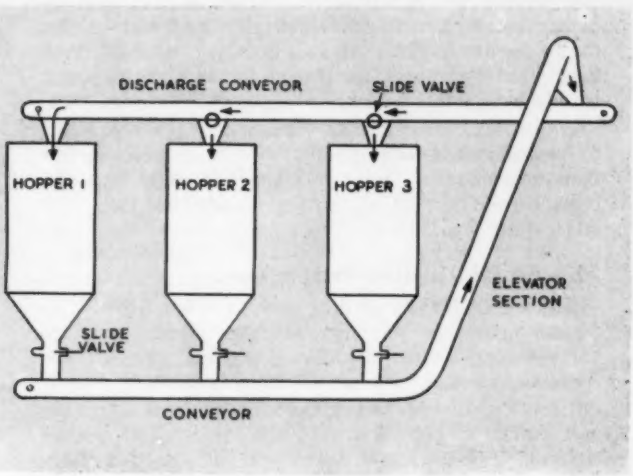



*Fig. 6. A circulating mixer for handling large batches. Material is distributed equally to each bin.*

In each case there must be adequate circulation of the charge within the mixer.

## Types of Mixer

Unfortunately, the application of these general principles to the operation of typical mixers is by no means simple because the two kinds of mixing are not easily separable in practice. Also, the flow of powdered or granular materials around blades and flights is not amenable to theoretical analysis. Basically three types of mixer are used: paddle or arm, tumbling, and circulating.

Many different kinds of arm mixer have been designed, of which the most common is the horizontal trough mixer. The shearing action is communicated to the batch by helical ribbon blades which also serve to propel the mixture horizontally and circulate it through the trough as shown in Fig. 4(a). Diffusive mixing probably occurs in the region immediately behind the blades where a defect in density will exist together with the necessary turbulent conditions. The extent of diffusive mixing and the scale of diffusion will increase with the operating speed. The trough mixer, which is suitable for batches of ordinary size, is less speedy in operation than a double cone mixer of similar power consumption, probably on account of the small scale of diffusion and limited turbulence. This type of mixer may give a more favourable comparison for mixing operations where the scale of scrutiny is large. It has the added advantage of slightly lower capital cost.

Tumbling mixers depend on tilting the batch beyond the maximum angle of repose. The simplest form is the drum mixer shown in Fig. 4(b). As the drum rotates the angle of repose increases until slip occurs in the batch. The material sheared from the main body of the batch slides down the inclined surface and diffusive mixing takes place, as may be seen in Fig. 8. The amount of shearing may be increased by fitting flights inside the drum or by including pebbles or balls in it. This mixer suffers from poor end-to-end circulation because the shear planes are all axial.

The double cone mixer is a more successful type of tumbling machine which is suitable for batches up to 1,000 cu. ft. It consists of a cylindrical ring to which two cones are attached (Fig. 4(c)) suspended in trunnions so that the whole assembly can be rotated about a ring diameter. The mixing action is at first similar to that which takes place in the drum mixer. As the maximum angle of repose is exceeded, shearing takes place and part of the charge begins to flow over the surface. As the angle of tilt increases, further slip occurs until finally the charge falls from one cone to the other. The mixing action has been ascribed to the bouncing of particles off the inclined faces of the cone. The bouncing action subjects the particles to rapid changes of velocity and acceleration and increases greatly the speed of diffusion. These large velocity and acceleration gradients and the consequent high degree of turbulence, which accompany the deceleration of the falling charge, are obtained for a relatively small expenditure of energy. The double cone mixer uses less power than comparable machines of other types: a figure of 3 to 4 h.p. is usual for a load of 1,000 lb.

The circulation of the charge in a simple double cone mixer is restricted by the relatively small scale shearing action and the symmetry of the casing. It may be improved by the inclusion of internal flights. This disadvantage is overcome in the rotating cube mixer (Fig. 5) and probably also in the recently developed twin-shell mixer, both of which are tumbling machines of asymmetrical construction.

For very large batches of more than 1,000 cu. ft. it may be advantageous to use an entirely different type of mixer. This comprises a number of bins or hoppers into which the batch is charged. Material is withdrawn from the bottom of the bins by means of a belt or conveyor, elevated and redistributed equally to each bin at the top (Fig. 6). Large scale mixing is achieved by

the process of redistribution. Diffusive mixing takes place as the redistributed material is scattered on the top of the batch. The method is slow. It is most effective when the ingredients are placed in separate bins and withdrawn in the proportion required in the mixture.

In practice, the choice of a particular mixer is likely to be influenced very greatly by considerations other than efficiency of mixing: contamination, ease of charging and discharging, ease of cleaning, expected life and capital cost.

## Mixing Dissimilar Particles

The whole of the foregoing discussion has been based on the mixing of two ingredients of similar physical and chemical properties. This is not an artificial concept because many operations involve the blending of different batches of the same product in order to obtain a uniform specification. On the other hand, it is common for the ingredients being mixed to have different properties, such as density, granule size, granule shape, and angle of repose. Most of these differences make mixing more difficult because the particles tend to segregate. The segregating action takes place at the same time as mixing and limits the completeness of mixing which can be obtained.

One of the most common causes of segregation is a difference in density of the particles. This results in a tendency for the heavier particles to sink to the bottom of the mix so that the distribution is no longer a matter of pure chance. Where the powder is closely packed, the particles have little freedom of movement so segregation is not marked. But, under the conditions where diffusive mixing takes place, the particles are free to move and considerable segregation will take place. The larger the scale of diffusion, the more marked will be the tendency for the heavier particles to separate. It seems probable that mixes of particles of widely different densities are best undertaken in machines with small scales of diffusion. Double cone and rotating cube mixers have one advantage in this respect, the reversal of the mixer body also reverses the gravitational field with respect to the particles. The rotating cube mixer has the added advantage of asymmetrical circulation.

Where the particles are of different size, it is less easy to explain the manner in which they behave. J. M. Coulson and N. K. Maitra[5] have noticed that in a drum mixer, the larger particles tend to migrate to the top. This may be due to the tendency for the smaller particles to pass between the larger ones under the effect of gravity. The smaller particles are mobile as soon as the powder has expanded sufficiently to allow them to pass between the larger particles. If the difference in diameter of the particles is sufficiently great, the smaller ones may be able to pass between the larger even when the large particles are close packed. For spherical particles it can be shown geometrically that it is possible for this to occur when the ratio of the diameters is less than 0:155.

In effect, a mixture containing particles of different size will display different scales of diffusion for the various sizes it contains. In the extreme case, for ratios of diameters less than 0:155, the scale of diffusion of the smaller particles is equal to the total volume of the mix, even when it shows no density defect. The smaller particles will not start to separate, however, unless they acquire kinetic energy. Mixtures of this kind are unstable and will separate rapidly if subjected to vibration in transport or storage.

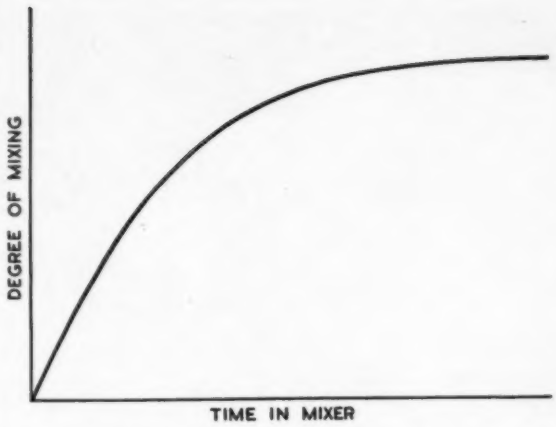



*Fig. 7. The degree of mixing varies with time mixed.*

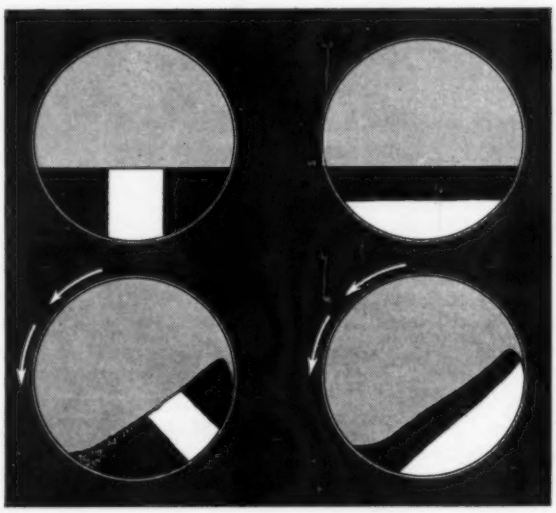


*Fig. 8a (left). A drum mixer loaded in this way starts to mix black and white components as soon as slip occurs. Fig. 8b (right). Loaded layerwise, only the black component slips: mixing does not start at once.*

It is common for powders to stick together in clumps or aggregates. Such aggregates may form because one ingredient is damp or sticky, or they may arise from electric charges carried by particles. Unless some method can be devised for breaking down the clumps, the best mixture that can be obtained corresponds to a random mixture of aggregates.

Aggregates are broken down to some extent in all mixing processes. The force required to shear the aggregate depends on the reason for the particles clinging together. In the mixer, the force acting to break up the aggregate is proportional to the acceleration gradient

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and the aggregate size. The best type of standard mixer to use in such a case is the double cone or rotating cube with their large acceleration gradients.

Where the aggregate-forming tendency is very marked and an exceptionally good dispersion of the ingredients is required, it may be necessary to subject the mix to even larger acceleration gradients. The simplest method of obtaining such gradients is by a small-scale shearing action such as that given by a pin disc mill.

## Rate of Mixing

A number of theories have been put forward to describe the approach to equilibrium conditions in a mixer. None of these explanations is wholly satisfactory, although that of A. Brothman[4] and his colleagues is probably adequate for shear mixing, while that of P. M. C. Lacey[9] applies to diffusive mixing. Each approach gives, as might be expected, an equation of the form

$$M = 1 - e^{-kt}$$

where $M$ represents the degree of mixing, $k$ is a constant and $t$ the time. Using this type of formula some agreement has been obtained with experimental results, although it seems likely that an equation containing two or more exponential terms is nearer the truth. The general form of this equation, which has been plotted in Fig. 7, makes clear the large increase in throughput which can be obtained by accepting a relatively small decrease in the degree of mixing.

A further economy in mixing time, with consequent increase in mixer throughput, may be gained by taking into account the mechanism of mixing when planning the method of loading the ingredients into the machine. As soon as the mixing operation starts, both shear and diffusive mixing take place. But diffusive mixing is almost ineffective until the scale of segregation is smaller than the scale of diffusion. In other words, diffusive mixing only performs a useful job when the volume over which diffusion takes place contains roughly the right proportion of the ingredients.

In some cases it is possible to load the machine so that this condition is fulfilled from the beginning of the operation and in this way much more speedy mixing can be obtained. In the case of the drum mixer, diffusion takes place in the material which shears off the inclined surface of the batch. If the ingredients are loaded as shown in Fig. 8a, the material which undergoes diffusion contains each of the ingredients. If the machine is loaded in layers in the manner of Fig. 8b, the early stages of diffusion serve only to mix particles of the same kind.

Side-by-side loading on the drum circumference is more difficult to carry out than layer loading. The double cone and rotating cube mixers show a further advantage because a fairly good sample of the ingredients is obtained in the first diffusion volume by layer loading. Mixing can be hastened if the ingredients are loaded in several alternate layers, but the increased speed so obtained may not merit the added complication and time involved in loading. If a rough mixture can be made by intermingling streams of particles of the different kinds as they flow into the mixer, a further considerable saving is possible.

## Unequal Mixes

So far, the majority of cases discussed have applied to materials to be mixed in approximately equal proportions. In many practical applications a small amount of one ingredient has to be dispersed in another. Sometimes the minor ingredient is required in concentrations less than 1%. In such cases, if the lesser ingredient is simply loaded into the mixer, the rate of mixing will be very slow. The efficiency of shearing actions depends on the number of shear planes which subdivide both ingredients and is roughly proportional to the ratio of the volumes of the ingredients: it is a maximum for fifty-fifty mixtures. The efficiency of shearing may also be increased by the method of loading; for example, by spreading the minor ingredient as a layer over the surface of the major one rather than leaving it in a small heap. Where mixtures must be made containing small quantities of one ingredient, it is usual to speed the process by first making a mixture of higher concentration, so that the ratio of volumes of the ingredients at each stage of mixing is nearer unity

## Assessing Performance

Because there is little experimental information available and theory is not yet highly developed, the choice of a mixer for a particular problem is still a matter of experiment, which may be guided by some of the points raised here. In assessing the performance of a mixer, it is best to have the specific problem in mind and to choose samples at random from the mix of about the same size as the scale of scrutiny required. These samples, if they are chosen in a truly random fashion, will give an estimate of the accuracy of all such subdivisions of the mix.

In order to follow the progress of mixing and so determine the minimum length of time required in the mixer, a less elaborate form of sampling is adequate. In this case relatively few samples—perhaps ten or twenty—are obtained at each stage of mixing. They are chosen, not at random, but to give the largest possible variation in composition. For example, in a drum mixer, samples would be taken from several positions along the axis of the drum and at several depths in the mix. Each set of samples should be obtained in the same manner. Analysis of the results obtained enables a graph to be constructed relating the standard deviation of the samples with time of mixing. From this graph an estimate may be made of the risk of error in composition of a volume equal to the scale of scrutiny after any particular time of mixing under given conditions. In this way the most economic mixing conditions can be determined.

### READING LIST

The following list covers the recent basic papers dealing with solid-solid mixing.


1. Adams, J. F. E. and Baker, A. G., *Inst. Chem. Eng.* Meeting 1955.
2. Blumberg, R. and Maritz, J. S., *Chem. Eng. Sci.*, 1953, **2**, 240.
3. Bonilla, C. F. and Weidenbaum, S. S., *Chem. Eng. Prog.*, 1955, **51**, 27.
4. Brothman, A., Wollan, G. N. and Feldman, S. N., *Chem. Metall., Eng.*, 1945, **52**, 102.
5. Coulson and Maitra, N. K., *J. Imp. Coll. Chem. Eng. Soc.*, 1948, **4**, 135.
6. Danckwerts, P. V., *App. Sci. Res. (Hague)*, 1952, **3A**, 279.
7. Danckwerts, P. V., *Research (London)*, 1953, **6**, 355.
8. Dukes, J. A., *Ins. Chem. Eng.*, 1951, **2**, 521.
9. Lacey, P. M. C., *J. Appl. Chem.* 1954, **4**, 257.

# The Fluid Energy Mill—

## FOR GRINDING SOLIDS TO SUB-SIEVE RANGES

by H. E. KINGSTON*

THE fluid energy mill, employing compressible fluid as a source of energy to reduce solid materials to sub-sieve particle ranges by effecting attrition between the solid particles being ground, was developed in the early thirties in the U.S.A. by the Micronizer Company of Moorstown, New Jersey. In the past twenty years there has been wide commercial acceptance of these mills because of their ability to pulverise solids which, due to physical characteristics, cannot be processed in mills such as Pebble, Ball, Hammer, Pin Disc and Roller Mills. Their ability to reduce materials to specifications in the lower micron particle ranges, an advantage not obtainable on mechanical milling equipment, is a major factor in their favour.

Up to now, the widest application in industry of fluid energy jet mills has been in the fields where a product having an average particle size of 5 microns (2,500 theoretical mesh) or less is desired, but there are numerous applications for these mills in producing products with particles sizes in the sieve range where special properties or results are desired. These include grinding with simultaneous separation of undersized impurities, control grinding to obtain a product with a minimum variation in particle size, and simultaneous drying and grinding using heated grinding fluid. The major number of installations existing today are for the simultaneous dry grinding and classification of solids. However, fluid energy jet mills may be used for reducing the particle size of solids suspended in liquids, or for coating one material with another and for effecting certain chemical reactions and changes in the physical characteristics other than a reduction in size.

A large variety of materials are processed in these mills. These include both non-metallic and metallic minerals and ores, metals, pigments, insecticides, fungicides, plastics, dyes, and numerous other organic and inorganic products, including cosmetics, antibiotics and other pharmaceutical products.

The grinding in all fluid energy mills results from attrition between particles of the material being ground, the energy being supplied in the form of compressed fluids entering the grinding chamber at high velocities through jet orifices. The variables in the design of these mills are as follows:

1. The form of grinding energy used.
2. The contour of the grinding chamber.
3. The number and size of the jet orifices.
4. The diameter of circle to which the jets are tangential.
5. Adjustment of the collection system.
6. Method of feed.
7. Feed rate.
8. Feed and ultimate particle size of material.

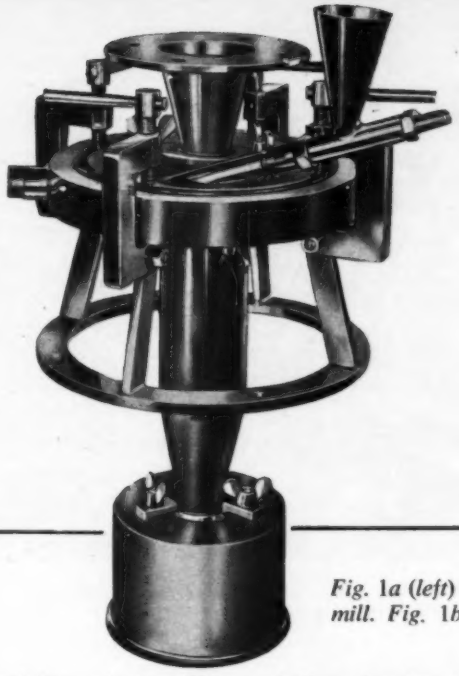
All these variables have to be taken into account in selecting a particular mill for a particular operation.

### Construction of the Micronizer

In principal, the construction of the Micronizer incorporates a flat cylindrical grinding chamber as shown in Fig. 1b. The mill shown is equipped with an aspirating Venturi feeder, which utilises the compressed fluid for injecting the feed into the grinding chamber. This method of feeding was used on the original jet mill and is employed in the majority of the commercial installations now in operation. Another method of feeding the mill is by means of a motor-driven compression feed screw. This is a recently developed improvement and offers two advantages on installations for processing materials that can be satisfactorily fed with it. These advantages are: a reduction in the total energy required; and the elimination of the necessity for delivering feed to the hopper at a controlled rate, as the feed rate can be accurately regulated with the screw. This type of feed can only be used where the material being fed to the mill forms an effective plug which prevents the grinding fluid escaping through the feed ports which would make the mill quite inoperable. The feed screw mechanism has, therefore, limited applications.

This type of grinding involves the action of gaseous fluid jets emerging from nozzles spaced around the

*F. W. Berk Ltd.



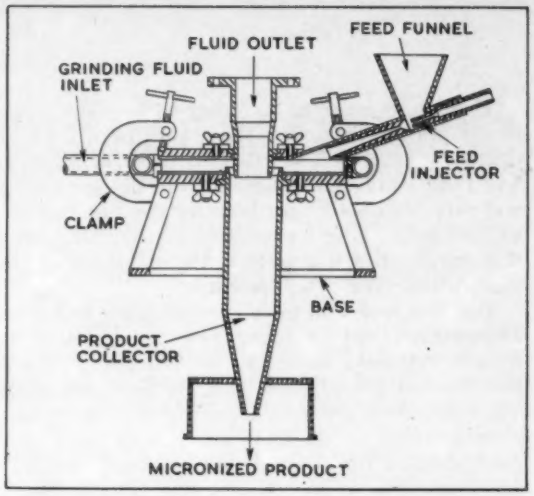



*Fig. 1a (left) shows the constructional details of a typical fluid energy mill. Fig. 1b (above) gives a section through the Micronizer mill.*

periphery of the shallow grinding chamber in which there is a circulating load of solid to be ground. The material is introduced through an opening in the top or bottom plate of the mill as near the periphery as possible, and the finely pulverised product and spent grinding fluid is exhausted through a circular concentric outlet in the top or bottom plate of the grinding chamber.

The nozzles are located in the outside wall of the grinding chamber with the axes of the jets pointing in the same direction of rotation and tangential to a circle of smaller diameter than the grinding chamber. The compressed gases issuing through these orifices maintain a high speed of rotation in the grinding chamber. Solids fed into the grinding chamber are accelerated by the rotating gases and are thrown to the periphery; a portion of the material coming into the zone of action of a nozzle is further accelerated tangentially and radially inwards, causing violent impacts between the particles thus accelerated and other particles which are circulating at a much slower velocity in a thin band near the periphery. It has been estimated that over 90% of the reduction in particle size in the Micronizer occurs within a fraction of an inch of the jet orifices. Observations also show that size reduction is independent of any grinding action with the wall of the chamber. The fines resulting from the continuing series of impacts are carried by the rotating gases inwardly in a spiral path towards the central outlet. Since the solids travel in the vortex at substantially constant tangential velocity, these are subject to an intense classifying action as they approach the outlet, the centrifugal force returning the oversize particles to the grinding zone while the entrained force of the gas carries the finer particles to the outlet. This dynamic classification mechanism is one of the chief reasons for the wide commercial acceptance of the fluid energy mill in the field of fine grinding.

The high efficiency of collection of finely ground products achieved with the Micronizer is another attractive feature. The spent grinding fluid bearing the fine solids is normally passed through a cyclone type collector which may be an integral part of the mill as shown in Fig. 1, or separate from the mill as would be necessary with the mill shown in Fig. 2. Practically all commercial installations operate with a primary collector efficiency of about 85%, and some installation efficiencies as high as 99% have been realised, even where the product has an average particle size of two microns or less. Normally the exhaust from the cyclone collector is cleaned by a bag filter or wet collector. In a few applications it may be advantageous to collect all the product in bag collectors, the secondary collector in this case being unnecessary.

Grinding energy for most commercial installations is supplied in the form of air compressed at 100 psi., temperatures ranging from below atmospheric to 700° F. Steam is used at pressures from 100 to 200 lb. per square inch with temperatures ranging from 400 to 1,000°F. A typical steam installation is shown in Fig. 4.

The volume of compressed fluid required to grind a unit weight of material is, in general, proportional to the kinetic energy of the fluid supplied. Since it is normally more economical to generate this energy in the form of superheated steam than by compressing air, superheated steam is used wherever the character of the material makes this feasible.

Generally, solids that are not friable at the temperature existing in the grinding chamber cannot be reduced satisfactorily. These include most fibrous materials, a number of metals, and some wax-like materials. However, a large number of materials that cannot be successfully processed in mechanical mills, due to the heat generated during milling, can be handled in mills either by using a cooled fluid as a source of energy, or as a result of the normal cooling effect of the expanding gases. Very hard abrasive materials are being ground to average particle sizes of less than 5 microns, and numerous others have been processed on an experimental scale, but in some cases it has been impossible to keep contamination from abrasion of the mill parts within the permissible range.

These mills are rated according to the inside diameter of the grinding chamber. This varies from 2 to 30 in. diameter. Table I shows different sizes of Micronizers and their energy requirement. Generally the capacities will vary from ½-4 lb. per hour for the 2-in. mill to 500 to 3,000 lb. per hour for the 30-in. machine. It is believed that the 30-in. mill represents the maximum economic size for this type of equipment.

The 2-in. and 4-in. mills were designed primarily for experimental work on expensive materials and to determine a material's suitability for processing. The 4-in. machine has proved itself ideal for the latter purpose. The Laboratory size mills are constructed throughout in stainless steel. Larger mills are manufactured in mild steel, stainless steel or other contemporary metals. The chief reason for using stainless steel is to prevent contamination of the product; penicillin, for example, is regularly ground on such mills (8 in.).

The abrasive wear on the internal surfaces of the mill is not normally excessive if the mill is correctly set, and mild steel construction throughout is often used. However, wear in many applications is sufficient to justify the use of special materials of construction and mills are designed to incorporate components which are easily replaced and inexpensive at the points where wear is most rapid.

Experience has shown that BHC and DDT formulations, sulphonamide drugs and other chemicals, and a large number of fungicides and insecticides have to be processed with compressed air at temperatures sometimes lower than atmospheric, due to their low softening

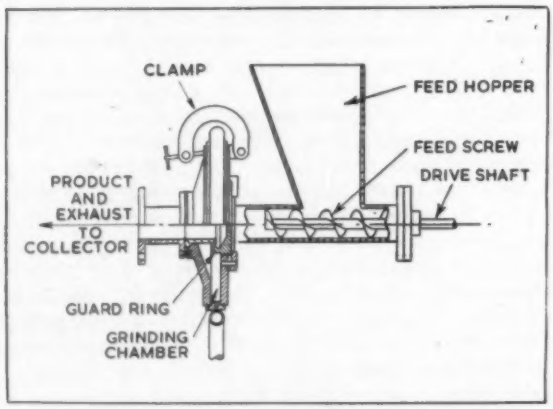



*Fig. 2. Screw feeder mill for non-plugging solids.*

**TABLE I. General Guide to Size and Grinding Energy Requirements of the Fluid Energy Mill.**

| Mill Size in. | Air Operation cu. ft./min. | Steam Operation lb./hour |
|---|---|---|
| 2 | 20 | — |
| 4 | 40 | — |
| 8 | 100 | 250 |
| 12 | 225 | 600 |
| 15 | 350 | 900 |
| 20 | 550 | 1,500 |
| 24 | 1,000 | 2,600 |
| 30 | 1,500 | 4,000 |

Note: 1. Volume of Free Air at 60° F. and 14.7 psia. Compressed to 100 psig.
2. Steam supplied at 150 psig. and 550° F.

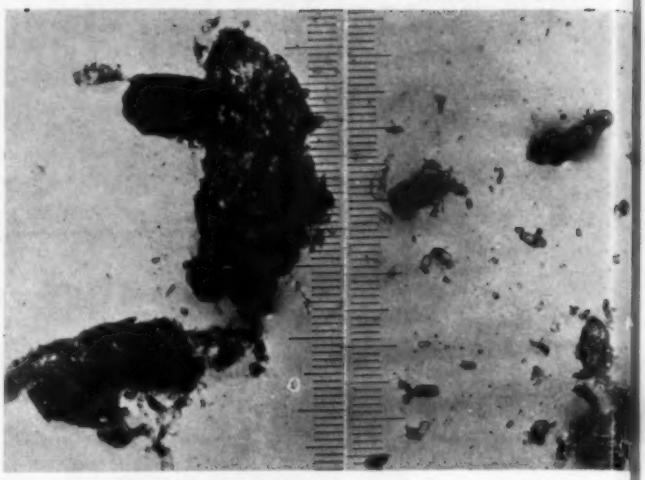


*Fig. 3. Photomicrograph showing unmicronised and micronised* PTFE 1 *sub-division* = 12μ.

or melting points. It is also desirable to use rubber-lined mills, collectors and all rubber Venturi tubes to reduce "build-ups" to a minimum, when BHC and DDT formulations are being pulverised. Fluid energy mills now in use for the commercial production of finely ground chemicals use compressed air as the source of energy. With proper precautions there is little danger of an explosion in the grinding chamber, the chief damage point being the bag type collectors normally used in sulphur grinding installations. To reduce damage to a minimum should an explosion occur, dust filters are usually located in the open and are equipped with explosion doors or vents and extinguishers. To reduce the risk of fire should an explosion occur, Micronizer installations used for grinding explosive materials are fitted with explosion suppression devices. These devices operate in about 15 milliseconds if there is any sharp rise of pressure (say 1 or 2 psi.) in the mill closed circuit. On the installations mentioned the positions of devices can be seen from Fig. 5.

Materials such as talc, iron oxide, cryolite, barytes, and Fuller's earth have all been processed using superheated steam as the source of fluid energy. Steam is normally used since it is usually a less expensive source of energy and the materials mentioned are not harmfully affected by the temperatures involved. Another advantage realised with steam is that a higher capacity can usually be achieved from the same size mill when steam instead of air is used. This is due to the fact that a greater quantity of energy may be supplied in the form of superheated steam without upsetting the conditions required for optimum grinding and classification (Table I). There are disadvantages in the precautions that must be taken, such as heating the mill up to operating temperature (which is necessary if a dried product is to be obtained), and the extra expense required to collect the solids carried in the spent gas from the cyclone collector.

## Operating Cost Factors

The major operating cost in all cases is that of the power used. The cost of energy will vary widely

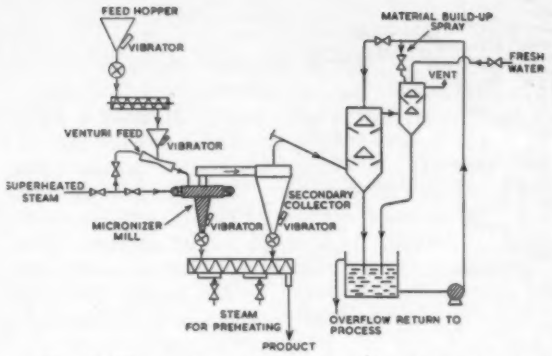



*Fig. 4. Plant using steam as source of energy.*

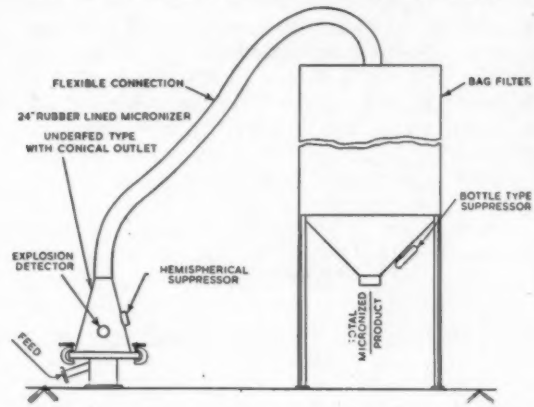



*Fig. 5. Plant arrangement for grinding explosion-prone materials.*

depending on the material being processed, the size of the feed, product particle size specification, and cost of fuel energy. The only satisfactory method to arrive at the cost of grinding any material is to carry out grinding trials. At first glance the cost appears high when compared with the price of particle size reduction in mechanical equipment (bearing in mind the fine state of division to which the material has been brought), however, the following example will serve to show that this is not the case when the new surface created is taken into consideration. If a 30 mesh (590 microns) material is reduced to say, 325 mesh (44 microns) which is considered fine grinding for most mechanical pulverising equipment, the number of particles are increased by 2,400 and the specific surface area is 118 times greater. If the 30 mesh material is reduced to an average particle size of 5 microns, the number of particles is increased by 1,643,000 and the specific surface area by 13,900 times. Therefore, based on the generally accepted theory that the energy required for grinding is proportional to the new surface created, it can be seen that 77.4 times more energy is required to grind a particle from 30 mesh to 5 microns as compared with grinding to 44 microns. Comparison will usually show that energy required for grinding to the sub-sieve range in fluid energy mills as compared with the fine grinding by mechanical mills is less than would be indicated by the above example. The reason for this is that for fine grinding in mechanical mills, high circulating loads are required and power above that required for size reduction must be supplied for classification and collection.

The range of variables that affect the fineness classification in fluid energy jet mills of the Micronizer type are:

1. The rotational speed in the grinding chamber.
2. The gas grinding flow.
3. The contour or shape of the grinding chamber.
4. Jet angles.

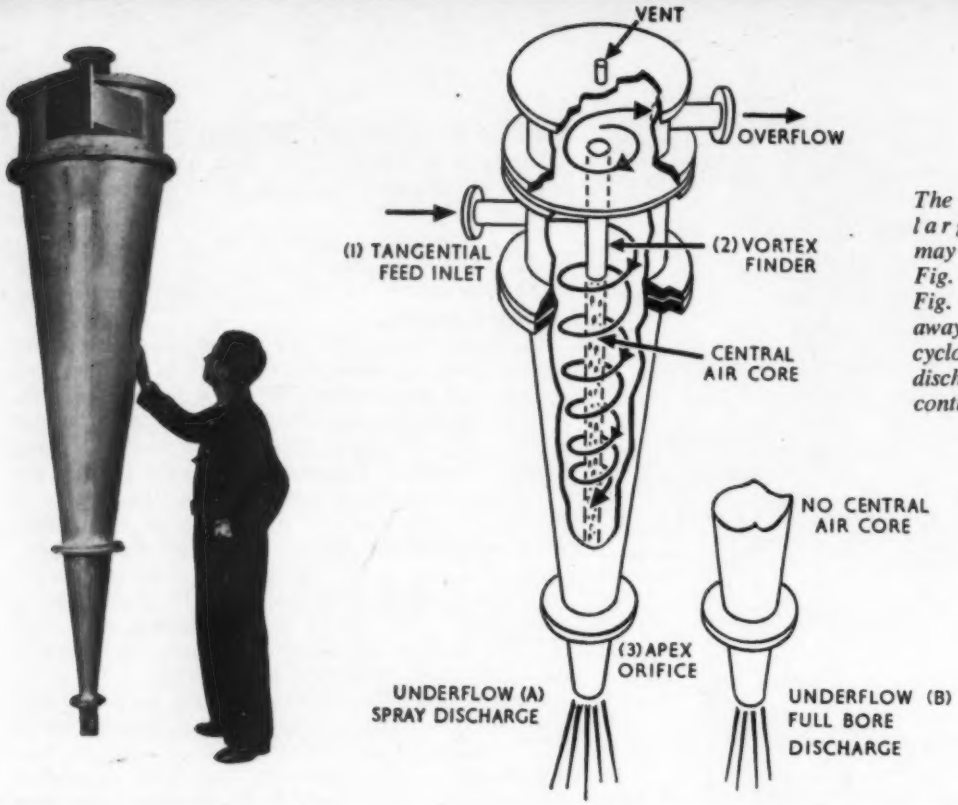
The control of the first and second factors is usually accomplished by controlling the rate of feed or gas pressure and temperature. The third factor is usually examined in initial experimental work to determine the design which will produce the optimum result in solving a specific problem. Variables affecting the third factor where the mill diameter is constant are: the number of grinding jets, the diameter of the circle to which these jets ar tangential, the design of the jet, grinding chamber height, location of the feed inlet and the contour of the top and bottom plates of the mill. From the number of variables given above it can be seen that it is desirable to base the design of a mill for solving a particular problem on experimental tests.

Product uniformity depends on the accuracy with which feed size, feed rate, pressure and temperature of the grinding fluid are controlled. The accuracy of control depends on the allowable variations in product specifications, but for satisfactory operation it has been found that the fluctuations should not exceed about 5%. Where it is impossible to obtain a feed having relatively constant physical characteristics, product uniformity may be maintained constant by varying the feed rate, volume, or pressure of the grinding fluid used. Quite large particles can be fed into the larger sizes of Micronizers. The only limitation is that the feed must not be of such a size that it will plug the feed mechanism. However, it is normally advantageous to pulverise to at least 10 mesh and, in some cases, to 100-200 mesh. One advantage of reducing the size to the minimum practicable with mechanical equipment is that this normally results in greater efficiency. Pre-grinding feed material to the minimum practicable size is very desirable when the maximum particle size allowable in the product is small and this specification must be rigidly adhered to.

Grinding solids to the sub-sieve range is becoming increasingly important, as manufacturers are finding numerous advantages resulting from increased surface area and small particle size. Fluid energy jet mills are the only answer at present to the problem of dry grinding solids to particle sizes on the lower micron range continuously and in large tonnages.

Although these mills have been predominantly used for the dry grinding of solids, a certain amount of work has been carried out on other applications which may be of interest in the future. Solids containing 30% moisture have been dried, ground and classified in one operation by using either superheated steam or air to produce a finely divided ground product.

Solid particles can be pulverised and coated with other solids or liquids in one operation to develop properties that are desirable in the finely ground product. Simultaneous grinding and mixing of solids can also be accomplished more efficiently than grinding the materials separately and followed by a subsequent mixing.




*The dimensions of a large hydrocyclone may be judged from Fig. 1, extreme left. Fig. 2, shows a cut-away diagram of a cyclone; (a) with spray discharging, (b) with continuous discharge.*

# The Hydrocyclone and its applications

by T. R. NAYLOR, M.A.(Cantab.)M.I.M.M.*

THE dry cyclone has been used for many years as a means of separating fine particles from air or other gases; the wet cyclone, in the fields of classifying and de-watering despite a patent application as far back as 1890,[1] is a comparatively recent development. The pioneering work was carried out shortly before the last war by Driessen[2] in Holland for the thickening of heavy media suspensions in coal preparation, and by Samson, Rastatter and Croup[3] in North America for the cleaning of paper pulp.

In principle the hydrocyclone, or liquid-solid cyclone, is a wet centrifuge consisting of a hollow cylindro-conical vessel into which the suspension to be treated is introduced tangentially and under pressure. This creates a rapid rotary motion of the pulp within the vessels as a result of which two vortices are formed; an outer one with its axial flow component directed towards the apex, and an inner one moving in the reverse direction. The heavier solid particles are thrown towards the outer vortex by the centrifugal force developed in the hydrocyclone and are discharged through an orifice in the apex, together with some liquid; the lighter solids are entrained in the inner vortex and leave the hydrocyclone, together with the balance of the liquid, through an axial overflow at its opposite end.

Fig. 2 illustrates the arrangement of a typical hydrocyclone: (1) the tangential feed inlet, either circular or rectangular in section, usually placed just below the top of the hydrocyclone; (2) the vortex finder, which discharges the overflow, and which generally extends to some point between the bottom of the feed inlet and the junction of the cylindrical and conical sections; and (3) the apex orifice, which discharges the underflow.

The normal functioning of a hydrocyclone is characterised by the formation of a central core through which air is drawn in via the apex orific and expelled through the vortex finder. In these circumstances both the overflow and underflow are discharged as spiral sprays as shown in Fig. 2a. If the apex becomes filled with settled solids a continuous underflow discharge with no spiral characteristics will be formed, and the air core will be absent (see Fig. 2b). The performance of

* *Liquid Solid Separations Ltd.*

a hydrocyclone is affected by the following factors:—

(a) *Feed Inlet Diameter or Area* which regulates the feed inlet velocity, and thereby the size of separation.

(b) *Vortex Finder Diameter* which controls the separation size by altering the radius of the inner vortex. Normally, the separation becomes finer as the size of these orifices is reduced down to a minimum, below which it again coarsens.[4,5] Increase in their size results in a coarser separation and a larger capacity; if this is carried beyond a certain point short-circuiting between the feed and the overflow will occur with loss of classification efficiency.

(c) *Apex Orifice Diameter* which controls the proportion of the total feed volume discharged as underflow, and thus its solid concentration. This proportion is a function of the relative diameters of the vortex finder and the apex orifice, and thus can be controlled by altering either; usually it is more satisfactory to change the latter. With reduction of the apex orifice diameter below a certain point the centrifugal force is reduced, and so, too, is the fineness of separation.

(d) *Apex Angle.* The smaller the included angle of the apex generally the smaller the pressure drop, and the greater the capacity at a given feed pressure; in practice apex angles range from 5 to 30 degrees, depending upon the purpose for which they are required.

(e) *Hydrocyclone Diameter.* The mechanism of the hydrocyclone is similar to that of a free vortex, in which the centrifugal force varies inversely as the radius. With feed inlets and vortex finders of the same relative proportions. the smaller the diameter of the hydrocyclone the higher the centrifugal force and the finer the separation.

Sizes in actual use range from 10 mm (0.4 in.) to over 1200 mm (4 ft.) in diameter, depending upon the mesh of separation and capacity required.

(f) *Feed Pressure.* This provides another means of controlling the feed inlet velocity and fineness of separation. The central air core of a small hydrocyclone will commence to form at a pressure equivalent to as little as 6 in. of water; in actual practice the usual minimum employed is about 2 psi, and the maximum 100 psi. Relatively high pressures may sometimes be advantageous in making separations in highly plastic or viscous suspensions, although under average conditions 30 to 40 psi is regarded as the usual maximum, whilst many fine separations can be efficiently performed at 10 psi or less.

(g) *Feed Dilution.* Fitch and Johnson[4] state that, under normal circumstances, feed dilution does not seriously affect the separation size until the percentage of solids (by volume) is 11% or more, although this statement is qualified in the case of suspensions of high plasticity or viscosity.

(h) *Solid Size and Solid and Liquid Density.* It has been shown that the Stokes Law relationship applies to solid particles settling in a hydrocyclone.

## Feed Rate Variables

The capacity or feed rate of a hydrocyclone depends on feed inlet and vortex finder diameter, cyclone pressure drop, and a constant related to the included angle of the apex (among other factors); Dahlstrom[6] gives an empirical equation. Generally speaking, capacity is very large in relation to hydrocyclone area or volume, ranging from a fraction of a gallon per minute for units 15 mm in diameter or smaller to over 4000 gpm for the largest 1200 mm units.

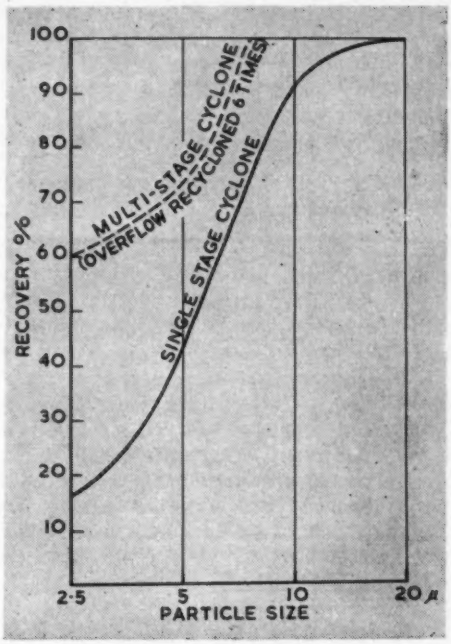



*Fig. 3. Influence of particle size on wet cyclone recovery.*

*Separation Size.* In order to indicate separation size and classification efficiency,[7] the method adopted in this article is to plot the percentage recoveries by weight of each size fraction as shown in Fig. 3. This curve represents the degree of separation which may be expected under average conditions with small diameter hydrocyclones (15−30 mm) operating at medium pressures of 10−30 psi, on 10% by weight suspensions of solids in the density range 2.5−3.5. Fineness of separation, and total solid recovery in the underflow may be increased by re-cycloning the overflow, one or more times—as shown in the upper curve of Fig. 3—although the classification will be less sharp as indicated by the greater flatness of the curve. Alternatively, if an underflow containing a minimum of undersize is required, it may also be re-cycloned, giving a recovery curve which is steeper in its medial portion, indicating sharper classification. Other methods of denoting particle separation size have been proposed by Fitch and Johnson,[4] Dahlstrom[6] and Tarjan;[8] the last two authors also give empirical equations for its calculation.

*Dewatering Efficiency.* As previously explained, the ratio of vortex finder apex orifice diameter controls the underflow volume proportion and thus the solid concentration of the underflow. The maximum will vary a good deal with the fineness and nature of the solids, but, under average conditions, an underflow of about 50% solids by volume is obtainable whilst still retaining the spray discharge shown in Fig. 2a, although with the continuous discharge (see Fig. 2b) the percen-

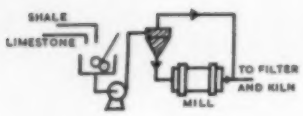



*Fig. 4. Wet grinding in cement manufacture.*

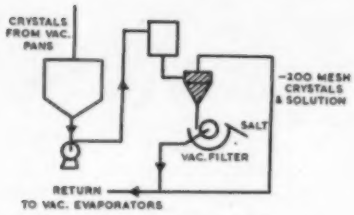



*Fig. 5. Classification in crystallisation processes.*

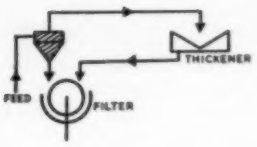



*Fig. 6. Hydrocyclone underflow used as precoat.*

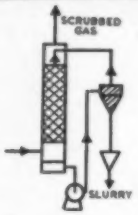



*Fig. 7. Treatment of scrubber liquor.*

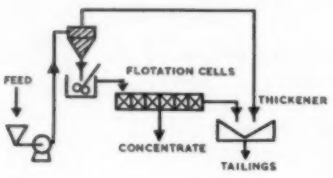



*Fig. 8. Desliming flotation concentrates.*

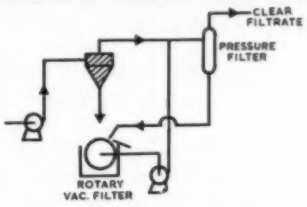



*Fig. 9. Desliming prior to filtration.*

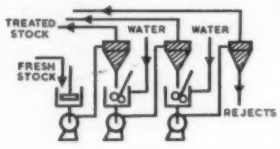



*Fig. 10. Cleaning of paper stock.*

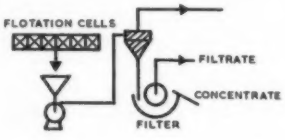



*Fig. 11. Dewatering of flotation concentration.*

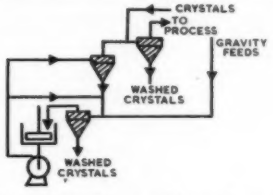



*Fig. 12. Series washing of crystallation products.*

tage of solids will be slightly higher, at the expense. sometimes, of losses in the overflow.

## Performance Characteristics

In addition to the very high centrifugal forces developed, which may be as great as 15,000 g, or more in small-diameter hydrocyclones, large shearing forces are also present. This combination makes the hydrocyclone particularly effective in ultra-fine separations such as "de-gritting" and "de-sliming," especially with feeds of high solid concentration or of a plastic nature. Their de-watering ability enables them to be used as thickeners or densifiers where the particle size is suitable.

It must be stressed, however, that, in general, solid recovery is limited to granular particles which normally settle independently, and does not include those whose settling rate is increased by flocculation or other form of aggregation, which the strong shearing forces in the hydrocyclone break up or nullify. These strong shearing forces are, however, a great advantage in de-gritting and de-sliming operations. With conventional methods using hydroseparators or other machines relying upon normal sedimentation, it is often necessary to add dispersants to avoid flocculation and to operate at high dilution in order to obtain the necessary separation. The hydrocyclone eliminates the disadvantages which arise with the conventional apparatus, disadvantages such as the large size of equipment, inflexibility of control, and the subsequent treatment difficulties which often occur owing to excessive dilution.

By contrast, the hydrocyclone will perform the same operations with greater efficiency, at lower dilutions, and without the use of dispersants. Its range of variables gives complete flexibility of control under most circumstances. Moreover, it is extremely compact and its initial cost is relatively low. Any number of units can be employed in series for further purification of the products if required.

Although the inability of the hydrocyclone to settle flocs or other aggregations limits its use in thickening, there are some cases (e.g., in the de-gritting of paper or other similar pulps) where this may prove a positive advantage. For example, if paper stock is treated in these centrifuges, which exert little or no shearing action, the paper fibre itself is concentrated, whilst the grit or or other reject matter is not removed. However, when treated in hydrocyclones, there is, due probably to the strong shearing forces present, relatively little concentration of the paper fibre, whilst the high centrifugal force enables even fine dirt particles of low density, such as "shive," to be rejected.

The ability to dewater down to about 50% solids by volume enables the hydrocyclone, subject to the limitations mentioned, to be employed in counter-current or other decantation processes for the washing of solids of a suitable size range. It can be used in crystallisation or other processes, where there is no objection to some return of ultra-fine solids to the circuit via the hydrocyclone overflow.

## Design, Maintenance and Control

Both Dahlstrom[6] and Tarjan[8] give equations for the calculation of the size of separation, but these should be used with caution since they do not include all the operating variables. The approach to each problem needs to be rather empirical, and for this reason units are generally provided with some convenient means for altering the main design characteristics, wherever possible, such as the diameters of the feed inlet, vortex finder and apex nozzle. These variables, together with feed pressure, and feed dilution, enables hydrocyclones performance to be regulated with requisite accuracy under most circumstances. The diameter of the apex orifice is the most critical factor, regulating as it does the density of the underflow. This density is usually controlled by means of interchangeable apex nozzles of different diameters, or by means of suitable valves manually operated.

Comparison between Hydrocyclones and other Liquid-Solid Separators.

*The following table may serve as a rough guide when weighing the merits of the hydrocyclone against other separators. The numerals represent order of choice for the various factors taken into consideration.*

| Consideration | Thickener or Hydro Separator | Mechanical Classifier | Hydraulic Classifier (Sizer) | Dynamic Centrifuge | Cyclone |
|---|---|---|---|---|---|
| Minimum Size of Separation ... | 1 | 5 | 4 | 2 | |
| Classification Efficiency ... | 3 | 2 | 1 | 2 | 2 |
| Dewatering Ability | 5 | 2 | 4 | 1 | 3 |
| Capacity ... ... | 3 | 3 | 4 | 2 | 1 |
| Power ... ... | 2 | 3 | 1 | 5 | 4 |
| Initial Cost ... | 4 | 2 | 3 | 5 | 1 |
| Maintenance Costs ... ... | 2 | 3 | 1 | 5 | 4 |

For certain specialised applications, however, automatic methods of underflow control have been devised. Examples are provided by the densification of heavy media suspensions where very close regulation of underflow density is sometimes required, and large-scale mining operations which are likely to entail wide fluctuations in feed composition.

These methods require the use of a rubber sphincter apex valve which is pneumatically controlled either by changes in the density of the underflow or by the partial vacuum of the air core which varies with the solid concentration of the underflow. Such automatic control methods add considerably to initial cost, and entail additional maintenance. Therefore it is preferable, under most circumstances, to provide sufficient pulp storage to enable a uniform feed density to be maintained. If it is also possible to obtain sufficient feed pressure by gravity, the combination of steady feed volume and density should enable consistent results to be obtained, without any need for more than the occasional altering of the apex or other orifices.

*Maintenance.* Plant experience to date has been principally in the field of mineral preparation where abrasive conditions are probably more severe than in most other industries. After some initial use of hard alloys as materials of construction, the tendency is now generally towards rubber-lined units; the lining is preferably replaceable, at any rate towards the apex orifice, where the wear is usually the greatest; wear also occurs at the feed inlet and at the vortex finder.

For laboratory and some other work, Pyrex hydrocyclones have been found quite suitable. In other instances, where pulps are only very slightly abrasive, some plastics, such as nylon, may be of value. Wear may also be reduced by operating at minimum feed pressures and by the preliminary removal of coarse material.

## Applications for the Hydrocyclone

The principle applications of the wet cyclone may be grouped under the following four main heads: 1. Classification; 2. De-sliming; 3. Degritting; and 4. Dewatering or decanting. Additional uses are specific gravity separations and, very occasionally, thickening.

*Classification.* Important uses are in closed and open circuit grinding particularly where a fine sized product is desired, such as would be the case in cement grinding (Fig. 4.). It has also been used for medium classification in crystallisation and filtration processes (Fig. 5.). One interesting proposal for filtration is the use of the coarse underflow to precoating (Fig. 6.). The treatment of scrubber liquid whereby only the fines are recirculated to a scrubber is a useful application for maintaining the efficiency of the scrubbing action and reducing maintenance (Fig. 7.).

*De-sliming.* Uses as a de-slimer are to be found in treatment of ores and coal prior to flotation (Fig. 8), where the advantages derived are increased capacity and flotation efficiency and reduced reagent consumption. In some cases where slimes adversely affect filter performance, the use of the wet cyclone may give increased capacity (Fig. 9.).

*De-gritting.* Typical examples of this kind are the benefication of china clay, de-gritting of milk of lime and the cleaning of paper stock and other fibrous materials such as asbestos (Fig. 10.). The latter applications are successful on account of the intense shear forces which are set up on the hydrocyclone. These forces are able to disintegrate the fibrous materials thereby allowing the unwanted solids to be released.

*Dewatering.* The dewatering of flotation concentrates is a widely practised application, the benefits in the case given (Fig. 11) being increased filtration capacity. Other examples, which can be classed as dewatering applications, are the washing of crystalline product (Fig. 12), and leashed uranium ore followed by ion exchange treatment.

It is not possible in this article to do anything more than just mention liquid/liquid separation with the hydrocyclone—on which some unpublished work has been done by Dahlstrom with some measure of success—or the use of the hydrocyclone as a heavy media separatory vessel, which is a field in itself.


1. Bretney, E., United States Patent, No. 453,105.
2. Driessen, H. G., "The use of Centrifugal Force for cleaning Fine Coal in Heavy Liquids and Suspensions, with special reference to the Cyclone Washer," *J. Inst. Fuel*, 1945, **19** (12), 33-45.
3. Rastatter, E. L., and Croup, A. H., "Hammermill Dirt Separator." *T.A.P.P.I.*, 1952, **35**, 223-227.
4. Fitch, E. B. and Johnson, E. C., "Operating Behaviour of Liquid-Solid Cyclones," paper to Amer. Inst. Min. Engrs. annual meeting, Feb., 1952.
5. Kelsall, D. F., "A further study of the hydraulic cyclone," *Chemical Engineering Science*, 1953, **2**, 254-272.
6. Dahlstrom, D. A., "Cyclone Operating Factors and Capacities on Coal and Refuse Slurries," *Trans. Amer. Inst. Min. Engrs.*, 1949, **184**,
7. Naylor, T. R., "The Hydrocyclone in Mineral Preparation," *The Mining Magazine*," July, 1954, 9-15.
8. Tarjan, G., "On the theory and use of the Hydrocyclone," *Acta. Tech. Hung.* (Budapest), 1953, **7**, 389-411.

# Perkin's Discovery and its Technological Consequences

**The centenary of the discovery of mauve by William Perkin is being celebrated this month. The major celebration takes the form of a conference patronised by the Duke of Edinburgh and sponsored by the Royal Society, the Chemical Society, the Society of Chemical Industry, the Society of Dyers and Colourists, the Royal Institute of Chemistry and the Association of British Chemical Manufacturers.**

WHEN young William Perkin decided a century ago to set up, with his father and brother, a factory at Greenford to make his newly discovered mauve, he set in train a rapidly increasing demand for new raw materials, and a need for new plant for the preparation of raw materials and the dyestuffs themselves The principal raw material for mauve was benzene. Methods of separating and refining this had been worked out by Charles Mansfield, and before his premature death in 1854 he had reached the stage of considering distillation in a continuous column.

The Perkin factory obtained commercial benzene from Glasgow and then purified it.

With regard to the construction of new plant, William Perkin paid this tribute to his brother: "I wish to mention that I had the good fortune of being associated with my brother, Mr. T. D. Perkin . . . and to his business habits and skill in devising and erecting new plant, the rapid development and success of this new industry was to a great extent due."

In the first Perkin venture it was necessary to nitrate benzene, a preparation already pioneered by Mansfield. The early method used glass bolt-head flasks. Soon nitration was carried out in a cast-iron pot with a horizontal shaft agitator. Later the more conventional pot with a vertical shaft agitator was used, and mixed acid was employed instead of the original sodium nitrate and sulphuric acid.

Perkin oxidised the aniline by mixing it in sulphuric acid solution with potassium dichromate. The black precipitate was collected upon shallow filters, washed and dried. This powder was then extracted with naphtha or ethyl alcohol, and here great difficulty was found in obtaining satisfactory jointing materials for sealing manholes. The other important member of the group of dyes obtained from the oxidation of aniline and its homologues was magenta. This required the treatment of a mixture of aniline with toluidine and this manufacture was undertaken by Nicholson's firm. From Hofmann's investigation on rosaniline, the base of magenta, arose a number of valuable derivatives.

A substantial change in activities was brought about by the discovery of methods of making alizarin in 1869 by Caro, Graebe and Liebermann, and independently by Perkin. Compared with the manufacture of mauve, the making of alizarin was much more difficult. Although Perkin had shown the world the first synthetic dyestuff, the rapid development of the large-scale production of alizarin constituted the outstanding technical triumph of the Perkin brothers.

The primary raw material for alizarin was anthracene. Although this was present in tar, it was quite unknown to the tar distillers. Perkin had prepared anthracene during research in 1855 and, therefore, had some idea of the method of obtaining supplies. He developed the technique of settling crystals from the final runnings of tar still, expressing neutral oil from the crystals by means of a hydraulic press, washing the ground cake with petroleum spirit, and distilling the residue with caustic potash. The anthracene was converted to alizarin by a number of process steps. One of the possible routes which Perkin favoured required the chlorination of the anthracene and the decomposition of the dichloranthracene with sulphuric acid. Another route demanded the oxidation of anthracene to anthraquinone and its sulphonation with fuming sulphuric acid. In either case the final steps required a fusion with caustic soda. The relatively large tonnages of these powerful reagents overshadowed the quantities of materials employed in the preparation of mauve.

The materials of construction used included glass, cast iron, timber lined with pitch, lead, earthenware, wrought iron and copper. Enamelled cast iron has not been noted in Perkin's well-illustrated accounts of the factory equipment, but Nicholson used such plant to heat magenta with sodium acetate and aniline to form aniline blue. There were two important manufacturers of such vessels at this period, and one of these, T. & C. Clark & Co. Ltd. of Wolverhampton, still outstanding today, had entered the field in 1839.

The sorts of unit plant employed in the industrial synthesis of these early artificial dyestuffs included conventional large glass flasks, cast-iron pot stills with worm tubs, specially developed cast-iron reactors with agitators, filters gradually becoming more sophisticated. Filter presses evolved from the early work of Needham in 1828 to commercial importance by 1860 when Needham and Kite were advertising their equipment for use by brewers, oil refiners and colour makers. The hydraulic press had already been widely used as a principal tool in oil-seed crushing. Crushing and grinding was done with edge-runner mills.

The next great advance in the dyestuffs industry was the development of synthetic indigo. On this the Badische company invested over £1 million and deployed a large army of chemists and technologists. A consequence in Britain was that the voices of woe called for a wide extension of scientific and technical training to meet the foreign menace, but the industry created by the genius of William Perkin was temporarily eclipsed by the onrush of the skilled battalions.

# Design Your Own Nomogram

It often occurs that simply measured variables are correlated by a complex equation, evaluation of which is both laborious and time-consuming. While chemical engineers often use special nomograms for repetitive calculations of this sort, comparatively few design their own when one is not available.

by D. B. PURCHAS, B.Sc., A.M.I.Chem.E.

THE design of a nomogram is often remarkably simple. Quite apart from the saving in time, a special nomogram may make it possible for a comparatively untrained person to carry out complex calculations essential, for instance, to the routine operation of a plant. The best known forms of nomogram are the Z-chart and the Parallel-line Chart. Other forms may be constructed for more complex equations. However, since these are comparatively rare and are more complicated, they are not considered here.

## Construction of Z-Charts

The Z-chart may be used for equations, containing three or four variables, of the forms

$$(i)\ \frac{a}{b} = c, \qquad (ii)\ a = b^c, \text{ and } (iii)\ \frac{a}{b} = \frac{c}{d}$$

*Type* (*i*). A typical three-variable equation of this type is

$$k = \frac{\mu}{s}$$

which relates the kinematic viscosity ($k$) of a liquid to its absolute viscosity ($\mu$), and its specific gravity ($s$). Fig 1 is a Z-chart for this equation; a straight line drawn through known values of $\mu$ and $s$ intersects the third axis in the equivalent value of $k$.

The theory of this type of chart may be understood by reference to Fig 2 which represents the equation $a/b = c$. $BCE$ is any index line, intersecting the axes as shown. Let the modulus ($M$) of any scale be defined as the length of line equivalent to unit change of the variable. Then,

$$x = M_a a, \qquad y = M_b b, \qquad z = M_c c$$

From the similarity of triangles $ABC$ and $EDC$ it may be shown that

$$\frac{M_a}{M_b} = \frac{M_c}{l - M_c c}$$

That is to say, the nomogram represents the equation $a/b = c$ provided

$$M_c = \frac{l M_a}{M_a c + M_b}$$

In constructing the nomogram, the moduli of the $a$ and $b$ scales, $M_a$ and $M_b$, are constant; the scales are therefore uniform and simple to calibrate. On the other hand, $M_c$ is not constant so that direct calibration of the $Z$-scale would be very laborious. However, it may be shown that

$$x = y\ \frac{M_a}{M_b}\ \ c = M_a a$$

By taking a constant value of $y$, it is possible to use this equation to plot a uniform scale representing $c$ along the $a$-axis; this may then be projected onto the diagonal $c$-axis from the fixed point $E$. In practice, it is usually

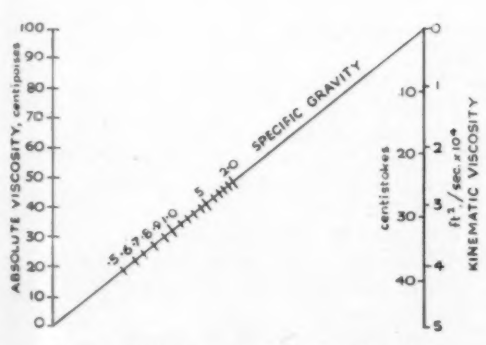



*Fig. 1. Viscosity conversion chart.*

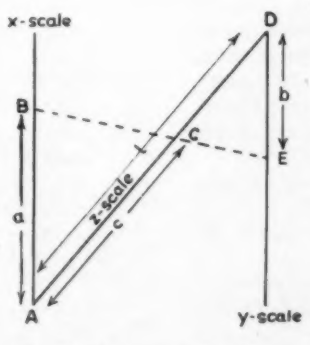



*Fig. 2. The equation* a/b=c.

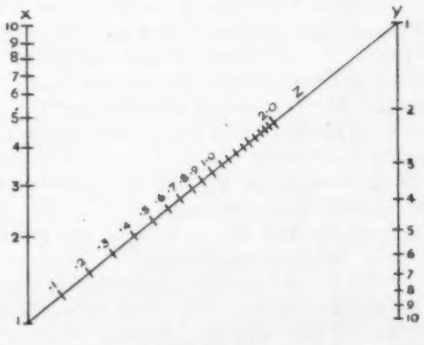



*Fig. 3. General equation* $x = y^z$.

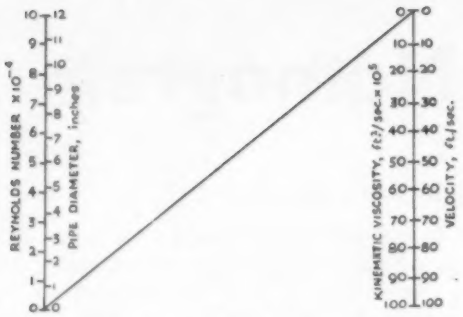



*Fig. 4. Chart for determination of Reynolds Number.*

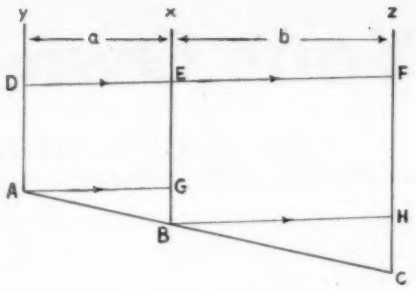



*Fig. 5. Solution of general equation* $a/b = c/d$.

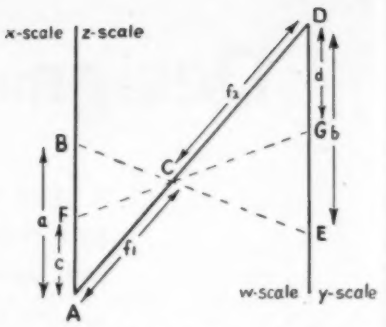



*Fig. 6. Parallel-line chart for the solution of* $f_1(a) = f_2(b) + f_3(c)$

best for $E$ to be the midpoint of the $b$-axis so that $y$ equals half the length of the $b$-axis.

The technique for constructing a Z-chart of this form may thus be stated:

1. Draw two equal parallel lines of any convenient length and spacing.
2. Subdivide these lines uniformly in units of $a$ and $b$ respectively, in each case starting at zero and going to the desired maximum but with the zero points at opposite ends.
3. Draw in the $Z$-axis by joining the zero points.
4. Calculate the moduli, $M_a$ and $M_b$, by dividing the scale length by the total number of units of $a$ or $b$.
5. Calculate the constant

$$K = \frac{M_a}{M_b} \times \frac{(\textit{length of } a \textit{ or } b \textit{ axis})}{2}$$

6. Along the $a$-axis, plot a temporary uniform scale for $c$ from the relationship that $Kc = M_a a$; the distance $M_a a$ is measured from $a = 0$.
7. Construct lines joining the midpoint of the $b$-scale to values of $c$ on this temporary scale. The intersections of these lines with the diagonal $Z$-scale give the desired calibration.

*Type (ii)* By taking logarithms and rearranging an equation of the form $a = b^c$ reduces to

$$\frac{\log a}{\log b} = c$$

Using a similar procedure to that above, it can be shown that a Z-chart may be constructed to represent this reduced equation. The technique for construction is the same but, in this case, the $a$ and $b$ axes must initially be subdivided in units of $\log a$ and $\log b$; calibration in terms of $a$ and $b$ then gives typical logarithmic scales When using the equation to calibrate the diagonal $Z$-scale, it must be remembered that the terms $M_a$ and $M_b$ are now the moduli of $\log a$ and $\log b$ and not of the simple variables $a$ and $b$.

Fig. 3 represents the general equation $a = b^c$. It may be used for several purposes:

(i) To raise any number to any power (within the range of the scales).

(ii) To evaluate the power relating any two numbers.

(iii) To find the logarithm of any number to any base. This may be seen since, if $a = b^c$, then $\log_b a = c$. Generally the only logarithms of interest are common, to the base 10, and natural, to the base $e$. A line joining $b = 10$, to any value of $a$ intersects the $c$-axis in the common logarithm of $a$.

*Type (iii)* Where there are four variables, construction of a Z-chart is simpler since all the scales are uniform. An example is Fig 4 which gives the Reynolds Number ($Re$) of a fluid moving through a pipe from its kinematic viscosity ($k$), its velocity ($V$) and the pipe diameter ($D$); the basic equation is $Re = VD/k$. To use the nomogram, two lines are drawn, one joining known values of the inner scale of each axis, that is $k$ and $D$; the second line is drawn from the known value of $V$, through the intersection of the first line and the diagonal, to cut the Reynolds Number scale at the required value.

In constructing this nomogram it was only necessary that the moduli of the four scales conformed with the equation

$$\frac{M_{Re}}{M_D} = \frac{M_V}{M_k}$$

This may readily be proved by reference to Fig 5 which represents the general equation $a/b = c/d$. In the diagram, $BCE$ and $FCG$ are any two index lines intersecting at $C$. Using the previous notation, it may be shown from the similarity of triangles $ABC$ and $DEC$, and triangles $ACF$ and $DGC$, that

$$\frac{M_a a}{M_b b} = \frac{M_c c}{M_d d}$$

This proves the validity of the equation relating the scale moduli.

The technique for constructing a Z-chart of this form may thus be stated:

1. Draw two equal parallel lines of any convenient length and spacing.
2. Fix the range of each variable so that the ratio $M_a/M_b$ equals the ratio $M_c/M_d$.
3. Subdivide the outer edge of one line uniformly in units of $a$ and the inner edge uniformly in units of $c$. In each case, start at zero at the same end of the line and go to the desired maximum.
4. Similarly with the second line, subdivide its outer edge in units of $b$ and its inner edge in units of $c$. This line must be calibrated with zero at the opposite end from the first line.
5. Draw in the diagonal reference line by connecting the zero points of the two parallel lines.

## Parallel-line Charts

Although a useful tool, the Z-chart has three major defects. First, it is applicable to only a limited range of equations; second, the vertical scales must start from zero; and third, and often most important, the useful section of the diagonal scale may fall at the compressed end and is thus not sufficiently sensitive.

The Parallel-line Chart is of wider application. Any equation which can be expressed in the form

$$f_1(a) = f_2(b) + f_3(c)$$

may be treated by this method. It is immaterial what the functions $f_1$, $f_2$ and $f_3$ are; they may, for example, be powers, roots or logarithms. The scales need not start from zero; only the useful range need be plotted, and, by judicious manipulation, may be expanded to occupy most of the space available, thus giving the maximum sensitivity.

To construct a Parallel-line Chart, it is only necessary that

(i) the moduli of the scales are such that

$$M_a = \frac{M_b M_c}{M_b + M_c}$$

(ii) the ratio of the distance between the $a$-scale and the $b$-scale to the distance between the $a$-scale and the $c$-scale equals $M_b/M_c$.

This may be established by reference to Fig. 6 which is assumed to represent the above equation. $ABC$ is a straight line passing through the zero points of the three parallel scales; $DEF$ is any index line. The lines $AD$ and $BH$ have been constructed parallel to $DEF$. Using the previous notation,

$AD = M_b f_2(b)$; $BE = M_a f_1(a)$; $CF = M_c f_3(c)$

From the similarity of triangles $AGB$ and $BHC$ it may be shown that

$$f_1(a) = \frac{BC}{AC}\ \frac{M_b}{M_a}\ f_2(b) + \frac{AB}{AC}\ \frac{M_c}{M_a} f_3(c)$$

This is the same as the original equation provided that $BC/AC = M_a/M_b$ and $AB/AC = M_a/M_c$. Hence it may be shown that

$$\frac{AB}{AC} = \frac{L_1}{L_2} = \frac{M_b}{M_c}$$

$$\text{and } M_a = \frac{M_b M_c}{M_b + M_c}$$

The technique for constructing a Parallel-line Chart may be briefly stated as follows:

1. Reduce the equation to the form $f_1(a) = f_2(b) + f_3(c)$.
2. Decide what ranges are required for the variables $a$, $b$ and $c$. Hence, calculate the ranges of the functions of the variables in the reduced equation.
3. Select a convenient length for the $b$ and $c$ scales.
4. From the scale length and the range of the functions calculate the moduli $M_b$ and $M_c$.
5. From $M_b$ and $M_c$ calculate $M_a$ and the spacing of the scales.
6. Construct the three scales to the specified length and spacing; calibrate the outer ones in terms of $b$ and $c$.
7. To calibrate the central $a$-scale, first locate any definite point on it by joining a value of $b$ to a value of $c$ and using the original equation. Then calibrate the scale from this known point.

The use of the Parallel-line Chart may be extended to equations containing more than three variables provided they can be expressed in the general form

$$f_1(a) = f_2(b) + f_3(c) + f_4(d) + \ldots\ldots\ldots f_n(z)$$

The method is to break the equation down into a series each containing three variables only:

$$F_1(A) = f_2(b) + f_3(c)$$
$$f_1(a) = F_1(A) + f_4(d)$$

Simple nomograms may be constructed for each of these secondary equations. By plotting these side by side with one or more common uncalibrated scales, which are reference lines only, a composite nomogram for the full equation is obtained.

Where the modulus of a scale is an awkward length, for example a logarithmic cycle $7\frac{1}{4}$ in. long, a modulus chart such as in Fig. 7 is very useful. Construction is simple, using the $C$ or $D$ scales of a slide rule to mark off the logarithmic scale of 10 in. modulus.

The parallel-line nomogram is very flexible and yet has its limitations. To illustrate both of these aspects, three examples are given. Examples I and II treat the viscosity conversion equation which was plotted as a Z-chart in Fig. 1; they illustrate how the sensitivity of one scale may be increased by sacrificing the range of another. Further, by comparison with Fig. 1, they show the relative merits of the two types of chart. Example III shows how this type of nomogram may be used for more than three variables, by reducing the equation to two or more simpler ones, as was done with compound graphs; it also illustrates the method used for dealing with powers and roots.

*Example I.* The viscosity conversion equation may be written

$$k = \frac{\mu}{s} \times 1.0764 \times 10^{-5}$$

where $k$ = kinematic viscosity in ft/sec.
$\mu$ = absolute viscosity in centipoises
$s$ = density in gm/cc, or specific gravity

Taking logarithms and rearranging,

$$\log \mu = \log k + \log s - \log (1.0764 \times 10^{-5})$$

The last term is a constant and may be ignored; allowance is automatically made for it in the vertical placing of the scales.

It is easiest to plot this if $k$, $s$, and $\mu$ are varied over complete logarithmic cycles. Thus, let $k = 0.00001$ to 0.001 ft/sec., $s = 0.1$ to 10, and $\mu = 1$ to 100 centipoises, which corresponds to a range of two units for the function (i.e. logarithm) of each variable.

Suppose the scale length is 10 in. Then,

$$M_k = M_s = 5 \text{ in.}$$

$$\text{Hence, } M\mu = \frac{M_k M_s}{M_k + M_s} = 2.5 \text{ in.}$$

Calculating the spacing of the scales,

$$\frac{L_1}{L_2} = \frac{M_k}{M_s} = 1$$

That is, the $\mu$-scale will be midway between the other two. Using the data, Fig. 8 has been constructed. The $\mu$-scale was calibrated starting from the point $\mu = 1$,

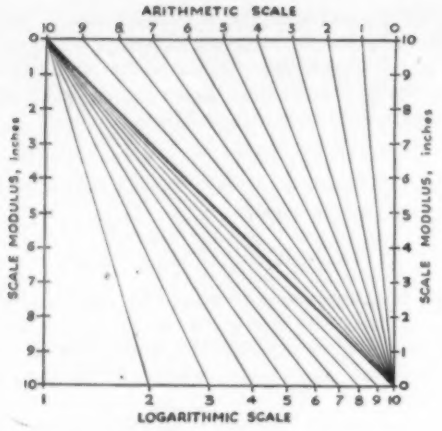



*Fig. 7. A useful modulus chart.*

*Fig. 8. (Example I). Chart to convert kinematic to absolute viscosity.*

which lies on a line joining $s = 0.1$ and $k = 0.00010764$. The disadvantage of Fig. 8 is that the useful range of each variable occupies only a part of the scale. Thus, the practical limits of the variables may be $k = 0.00002$ to 0.0005, $\mu = 1$ to 100, and $s = 0.50$ to 2.0. This corresponds to 70%, 50%, and 30% of the respective scales.

*Example II.* Referring again to the viscosity conversion equation, let $k = 0.00002$ to 0.0005 and $s = 0.50$ to 2.0. Previously, with a 5 in. modulus for a $k$-scale, this occupied only 70% of 5 in. Therefore the modulus now is

$$M_k = \frac{5}{0.7} = 7.143\,\text{in.}$$

$$\text{Similarly, } M_s = \frac{5}{0.3} = 16.667\,\text{in.}$$

$$\text{Therefore, } M_\mu = \frac{M_k \; M_s}{M_k + M_s} = 4.99\,\text{in.}$$

The spacing of the scales is given by

$$\frac{L_1}{L_2} = \frac{M_k}{M_s} = \frac{7.143}{16.667} = 0.428$$

In constructing Fig. 9, the $k$ and $s$ scales were calibrated directly since the ranges were fixed. The $\mu$-scale was calibrated starting from $\mu = 1$, which lies on a line joining $s = 0.5$ and $k = 0.0000214$. It will be seen that the upper limit of the $\mu$-scale is now only 93 centipoises; but a 10 in. scale needs lengthening by only 7/32 in. to extend the range to 100 centipoises.

*Example III.* In an investigation of a sinter plant, it was necessary to measure frequently the permeability of the porous bed through which air was sucked. The permeability is defined as

$$P = \frac{Q}{A}\left(\frac{h}{s}\right)^{0.6}$$

where $P$ = permeability, in Bed Permeability Units
$Q$ = air flow, in cu. ft. per minute at 60° F
$s$ = pressure drop across the bed, in inches W.G.
$h$ = thickness of the bed, in inches
$A$ = cross-sectional area of the bed, in sq. ft.

The airflow was measured using a 7.40 in. diameter orifice in the 8.0 in. diameter duct, the contraction coefficient being assumed equal to 0.60; correction for temperature was made from thermometer readings. For a given orifice installation, it may be shown that

$$Q = K \cdot \left(\frac{p}{T}\right)^{0.5}$$

where $Q$ = air flow, in cu. ft./sec. at N.T.P.
$K$ = a constant
$p$ = pressure drop across the orifice in inches W.G.
$T$ = air temperature, °K

$$\text{Hence, } P = K'\left(\frac{p}{T}\right)^{0.5}\left(\frac{h}{s}\right)^{0.6}$$

where $K'$ is a constant. A nomogram may readily be constructed for this equation if it is re-stated as follows:

$$P = \frac{K'}{K} QD \quad \ldots\ldots\ldots\text{Equation (i)}$$

$$\text{where } Q = K\left(\frac{p}{T}\right)^{0.5} \ldots\ldots\ldots\text{Equation (ii)}$$

$$\text{and } D = \left(\frac{h}{s}\right)^{0.6} \quad \ldots\ldots\ldots\text{Equation (iii)}$$

For each of these equations, a nomogram may be constructed; these, arranged side by side in one diagram as in Fig 10, give the complete nomogram for the full equation.

(a) Taking logarithms of Equation (ii) and rearranging,

$$0.5 \log p = \log Q + 0.5 \log T + \log K$$

If $T = 50°$ to 300° C (i.e. 323° K to 573° K), it will be seen from the modulus chart in Fig. 9 that this is 25% of a logarithmic cycle. Therefore, with a 10 in scale, the modulus of $\log T = M_T = 10/0.25 = 40$ in.

In the above equation, the $T$ term is 0.5 log $T$. The modulus of this, $M'_T$, must be twice the modulus of log $T$, since the modulus is the length of line equivalent to unit change of the function. Therefore, $M'_T = 40/0.5 = 80$ in.

Similarly, if $Q$ varies from 20 to 35 cu. ft. per second at N.T.P., this is 24.4% of a cycle, and $M_Q = 10/0.244 = 41$ in. Therefore,

$$M'_p = \frac{M'_T \; M_Q}{M_T + M_Q} = \frac{80 \times 41}{80 + 41} = 27.10\,\text{in.}$$

and $M_p = 0.5 \times M'_p = 13.55$ in.

*Fig. 9 (Example II). Nomogram for viscosity conversion.*

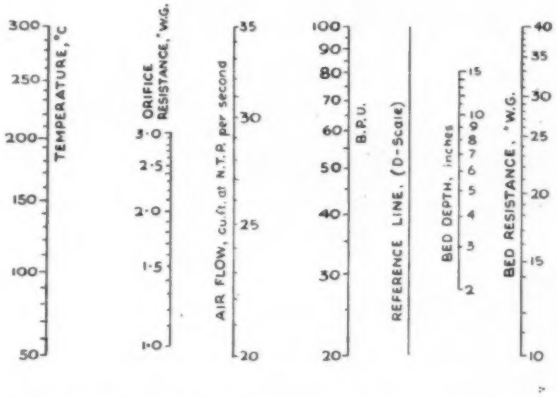



*Fig. 10 (Example III). Permeability chart; a nomogram with more than three variables.*

The spacing of the scales is given by

$$\frac{L_1}{L_2} = \frac{M'_T}{M_Q} = \frac{80}{41} = 1.95$$

(b) Taking logarithms of Equation (i),

$$\log P = \log Q + \log D + \log K'/K$$

If $P$ varies from 20 to 100, this is 70% of a logarithmic cycle, and $M_P = 10/0.7 = 14.3$ in. Since $M_Q = 41$ in., then

$$M_D = \frac{M_Q\, M_P}{M_Q - M_P} = \frac{41 \times 14.3}{26.7} = 22 \text{ in}$$

The spacing of the scales is given by

$$\frac{L_3}{L_4} = \frac{M_Q}{M_D} = \frac{41}{22} = 1.865$$

(c) Similarly, Equation (iii) gives

$$\log D = 0.6 \log h - 0.6 \log s$$

If $s$ varies from 10 to 40 in. W.G., this is 60.4% of a logarithmic cycle. Hence, $M_s = 16.55$ in. and $M'_s = 16.55/0.6 = 27.60$ in. Therefore,

$$M'_h = \frac{M_D\ \ M'_s}{M_D + M'_s} = \frac{22 \times 27.6}{22 + 27.6} = 12.23 \text{ in.}$$

and $M_h = 0.6\ M'_h = 7.34$ in.

The spacing of the scales is given by

$$\frac{L_5}{L_6} = \frac{M_D}{M_s} = \frac{22.0}{27.6} = 0.80$$

Sufficient data is now available to construct the seven scales. The ranges of $T$, $Q$, $P$, and $s$ were fixed, so that direct calibration is possible. The $D$-scale is a reference line only and is left uncalibrated. To calibrate the $p$-scale, the point $p = 1.0$ is first located by joining $T = 323°$ to $Q = 20.6$. Similarly, to calibrate the $h$-scale, the point $h = 10$ in is located by joining $s = 17.24$ in. W.G. with the intersection of the $D$-scale and a line joining $Q = 35.0$ and $P = 100$.

Fig. 10 represents the completed nomogram; for convenience, the temperature scale has been calibrated in degrees Centigrade instead of degrees Absolute. To use this diagram, a line is drawn from the temperature through the orifice resistance and extended to give the air flow; a second line is drawn from the bed resistance through the bed depth and extended to cut the reference line; finally, the intersection with the reference line is joined with the air flow to cut the permeability scale at the required point.

# BRITAIN'S FIRST SYNTHETIC RUBBER PLANT

THE plans of International Synthetic Rubber Co. Ltd. for making GR-S rubber are now approaching finalisation. Subject to permission being given by the planning authorities, Britain's first plant for producing synthetic rubber will be erected at Fawley at a cost of £5 million. A 50-acre site is to be developed, which the Esso Petroleum Co. have made available near their Fawley refinery. Butadiene will be produced in the refinery and piped into International Synthetic's copolymer plant. The necessary styrene is to be supplied by Forth Chemicals and Shell. Initially, production of 50,000 tons of GR-S is planned, which will mean a saving of $30 million a year. The plant, which will employ about 320 people, should be operating by 1958.

The International Synthetic Rubber Co. was formed by four firms which manufacture tyres, namely Dunlop Rubber, Goodyear Tyre and Rubber (Great Britain), Firestone Tyre and Rubber, and Michelin Tyre. Its chairman is Mr. G. E. Beharrell, who is the managing director of Dunlop Rubber. There is talk of other British firms belonging to the rubber manufacturing industry joining this production venture which almost certainly will sell some part of its output to non-shareholding firms.

Commenting on the news about the projected plant, Sir Leonard Sinclair, chairmen of Esso Petroleum Co. Ltd., remarked that not only would it establish a new industry in Britain but it could help our foreign exchange position. It provides, he said, yet a further example of the benefits to the nation's economy resulting directly from the post-war capital investments made by the oil companies in Britain.

**AMERICAN LETTER**

*Dr. Lincoln T. Work*

# Twilight of the Pilot Plant?

Our American Correspondent discusses the evolution of the pilot plant, its value as a research tool and its place in modern chemical engineering developments

DURING the past forty years, chemical engineering practice has gone through a transition from what was really industrial chemistry to a reasonably matured profession. It was natural that a number of techniques would develop which would serve their immediate purpose, only to be modified later as conditions changed. One of these is the pilot plant. Some time ago, your correspondent heard this title—"Twilight of the Pilot Plant"—and it intrigued him.

The pilot plant is distinctive to chemical engineering. It took form as a definite entity to meet the need for transition from laboratory glassware to the commercial plant at a time when the knowledge of engineering materials suitable for large-scale chemical equipment was extremely limited. The pilot plant became a means of preparing samples of a grade that would be produced commercially, and it was even employed for some initial small-scale production. Market research was unknown. There was no way to predict the growth rate and ultimate value of the market for new products. For these reasons, the pilot plant found its valued place.

The classification of steps into unit operations went hand in hand with the pilot plant. The strengths and weaknesses of various types of equipment in each unit operation could be established. Gradually, order came out of chaos and there was a degree of standardisation. Some special types of problems required specially designed equipment. This was particularly true for reaction equipment.

The science behind these unit operations took definite form. Calculations for such things as fluid flow and heat transfer became more soundly based. Thus, prediction was made quite safe in many cases.

The cost of research and the time required to bear fruit became the subject of study. Seven years from the idea to profits was a by-word in this concept. Research directors became conscious of the accumulating cost of a project during the pilot plant stage, and their response was to speed up the work so that the expenditure would soon turn to profit. The slogan, "Make your mistakes on a small scale and your profits on a large one" was repeated *ad nauseum*.

The "new look" in pilot plants took shape around and during World War II. Speed was the essence in new construction. Process change and new processes could not await exhaustive test. Surprisingly, the accumulated data and the personal experience of engineering staffs made it possible to design new plants without extended testing in pilot plants. In one case, a risk of several million dollars was taken without pilot plant data on the doubtful steps. When the plant started, the revision that was necessitated to obtain optimum effectiveness cost a little over six per cent of the investment. Preliminary estimates for pilot plant construction and operation during a test period had also been calculated when the decision to skip the pilot plant had been made, and they were slightly in excess of the revision cost. Above all, two years of production had been saved. In such a case the calculated risk paid big dividends.

Experimental data is often required before it is safe to make a design. Sometimes it is best to expand operations from the laboratory scale, through a pilot plant, to the operating size. This is true where hazards of unknown magnitude may exist, calling for caution in the growing scale of operations. In the case of valuable chemicals, notably the synthetic pharmaceuticals, the pilot plant may be set up for the minimum estimated volume of business, and increased later for the normal business volume.

There is, however, a more general tendency to break the process down into steps which may be separately engineered. Some of these steps may be easily designed from experience. Others may require some laboratory data which can be obtained by experiments at the bench. A few may require test in pilot size equipment.

It is apparent from this discussion that the pilot plant represented a phase in the maturing of a profession. It has been weighed and found in many cases to have been carried to an extreme. A balance has been struck. The formal pilot plant to synchronise all of the steps has a place, but it is much more limited in extent. It has been replaced by common data and experience often taken from related but different processes, by piloting the unknown steps to fill in the gaps in experience, and by working at the desk and drawing board to integrate these into a process and plant.

Though some experts think that the pilot plant is approaching its twilight, most chemical engineers would regard it as altogether premature to begin thinking in terms of the obsolescence of pilot plants. Only the future can show if and when the pilot-plant concept will go into oblivion.

# TONNAGE OXYGEN PLANTS

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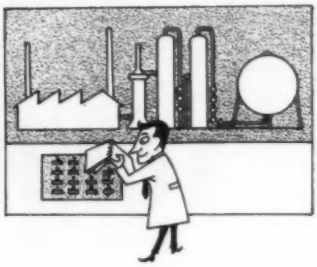
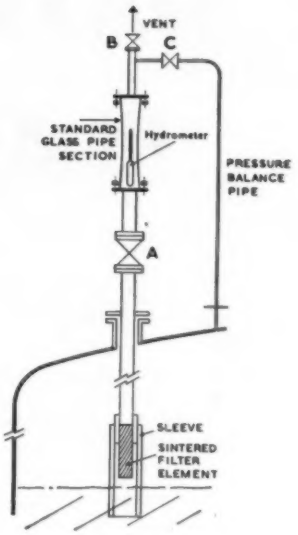
# PROCESS ENGINEER'S NOTEBOOK



## Sampling Device for Closed Reactor Incorporates a Self-Cleaning Filter

IN a batch reaction process carried out at 30-40 psig solid and liquid reactants were used. The desired end product was the liquid. It was found that the best indication of completion of reaction and of product quality was its specific gravity. The problem was to sample the vessel contents without interrupting the reaction. The sample had to be a clear solution suitable for gravity determination by hydrometer. After the test it was desired to return the sample to the vessel. The layout had also to be arranged so that, in the future, the process could be controlled automatically on the basis of density measurement.

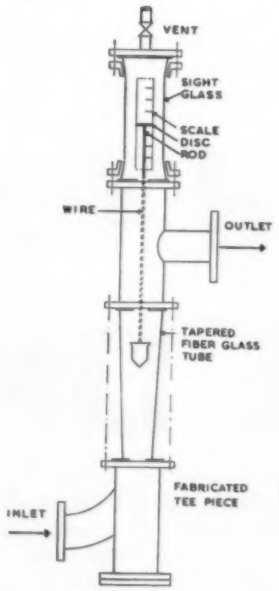
In the scheme illustrated, the tube connecting the sampling vessel to the reactor contents terminates in a sintered metal cylinder. The sampling vessel, which contains the hydrometer, can be isolated at its lower end from the reactor by means of a valve *A*; at its upper end are two further valves *B* and *C*, one connecting the sampler to atmosphere and one to a source of pressure. In one case, the vessel itself was used as a source of pressure. In operation, valves *A*, *B*, and *C* are normally closed. When a sample is wanted valve *B* is opened, and then valve *A*. When a sufficient quantity of clear liquid has been forced up into the sampling vessel, valve *A* is closed and the reading taken. After the reading has been taken valve *B* is closed, valve *C* opened, then valve *A*. As a result of pressure equalisation in the system, the sample is removed from the sampling system and drains finally from the sintered tube end. (See schematic diagram right).




## Improvised Flow-Meter Uses Fibre-glass Fishing Rod

THIS idea was devised to overcome a hold up in production caused by a broken Rotameter tube in a distillation column flow-line. In this particular instance delivery of replacement tubes had been delayed, and as a result a repair was necessary to keep the unit on stream. The broken glass tube was replaced by a tapered fibre-glass tube obtained from fishing-rod manufacturers. Fortunately, the largest tube available had a cross-section similar to that of the original Rotameter tube. A new plummet with slightly altered dimensions was turned out of aluminium bronze on a lathe, drilled and tapped to take a piece of sif-bronze welding rod which was threaded at both ends. The edges of the fibre-glass tube were made square by careful filing, and finally by rubbing down on fine sandpaper fixed to a flat plate. The fibre-glass metering tube was supported between two flanged tee-pieces, the lower one being fabricated on site to allow the assembly to fit the existing pipe work connections.

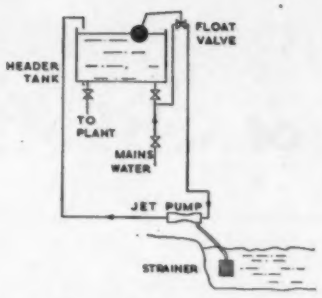
To the upper tee was fitted a standard glass pipe work connection into which the top of the welding rod projected. A thin disc cut from shim stock was forced on to the end of this rod to act as a pointer. The improvised instrument was calibrated and a paper scale attached by adhesive to the glass tube. In service, the instrument has done all that was required of it. Care is necessary, however, in making the joints between the fibre-glass tube and the tee-piece flanges. The constructional details of the Rotameter tube are illustrated in the schematic diagram left.




The application of the fibre-glass taper is limited by the resistance of the material to deterioration by the fluids handled in the flow meter. Thus, would-be users of the idea are advised to satisfy themselves on this point. With some fluids and solvents there is a tendency for the laminate to swell slightly and this may reduce the diameter of the taper tube with a resultant alteration of the calibration. This factor, however, will not be serious for the majority of applications for which fibre-glass is suitable. The application outlined above is a low pressure one, although it is possible that higher pressures could be accommodated by re-inforcing the taper.

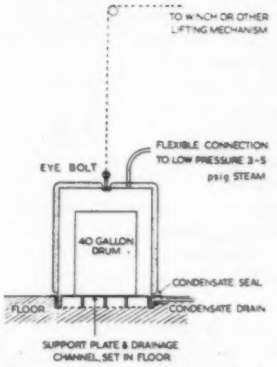
## Jet Pump Solves Water Supply Problem

A SMALL pilot plant required a cheap supply of cooling water. Mains water was available, but in the quantities required by the plant would have been unnecessarily expensive. Water for cooling purposes was available from a nearby canal. A variety of objections existed to the installation of a pump to supply the plant with cooling water from that source. An inexpensive compromise was arrived at by using a jet-pump, utilising mains water as the pumping fluid, to pump canal water to a header tank




supplying the plant. The ratio of the canal water to mains water was 4:1, so that a considerable reduction in cooling water cost was effected.

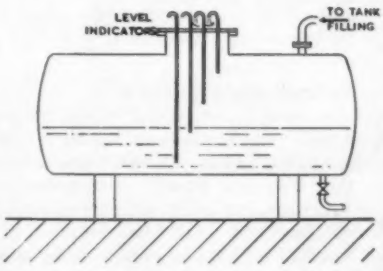
## Cheap and Rapid Drum Heater


TO WINCH OR OTHER LIFTING MECHANISM
FLEXIBLE CONNECTION TO LOW PRESSURE 3-5 psig STEAM
EYE BOLT
40 GALLON DRUM
CONDENSATE SEAL
FLOOR
CONDENSATE DRAIN
SUPPORT PLATE & DRAINAGE CHANNEL SET IN FLOOR

THIS is a cheap and rapid method of heating drums which have to be heated prior to emptying. The equipment consists of a heating cap (which can be a cut down 80-gallon drum), a lifting means for raising or lowering the cap and a base set into the floor. The latter serves as a low pressure steam trap and, incidentally, protects the floor from damage through continual handling of drums. The larger container has a 1 in. thickness of lagging and has an eye-bolt fixed in its closed end for lifting, together with a flexible connection for the low pressure steam supply. The base, which is constructed of ¼ in. M.S. plate, is circular and has a circular channel welded to its periphery. The depth of the channel should be about 3 in., width 1 in. and its mean diameter equal to that of the cap. The channel, which is normally filled with water, has a condensate overflow connection. In operation, the drum is placed end-wise on the base and the cap lowered over it, allowing the rim to settle in the channel. Steam is applied to the cap and shut off when the drum has received the necessary heating. The cap may now be raised and the heated drum removed.

## Fumes Indicate Tank Levels and Prevent Over-Filling

THIS idea avoids the installation of tanks contents gauges in cases where the main purpose of the gauge




is to prevent the tank from being over-filled during the filling operation. The method is successful for liquids such as nitric acid and phosphorus oxychloride which fume readily on exposure to the atmosphere. The arrangement consists of a number of small bore tubes of resistant material with their lower ends at different levels in the tank. During the filling operation air will be displaced from the tank through the tubes. Consequently, fumes will appear from their open ends. As the level of the liquid in the tank rises, so the ends of the tubes become submerged in turn. When the end of a tube is thus sealed off, fumes cease to issue from its open end. The cessation of fumes discharging from the shortest tube is an indication that the tank is full.

## Telephone Monitoring System Eliminates Week-end Visits to Pilot Plant

A TELEPHONE monitoring system has been devised which eliminates the need for twice daily week-end inspections of a process under investigation on the pilot plant scale at a well-known oil company. The process employs a continuous recording mass spectrometer for the analysis of a number of streams. The spectrometer requires a very high vacuum which is attained after prolonged pumping-down by means of combined diffusion and mechanical vacuum pumps. Thus if the unit has been closed down at week-ends, it would have resulted in the loss of the several days required for pumping-down.

The problem was further complicated in that the vacuum system included two refrigerated traps; one using dry ice and the other liquid nitrogen. The nitrogen trap, which is fed automatically with liquid nitrogen, is essential for the attainment of the high vacuum required by the spectrometer. Furthermore, the dry ice and liquid nitrogen traps had only sufficient capacity to maintain the required low temperatures for some 10 hours should the liquid nitrogen supply fail. One final point for consideration was that the electronic circuitry in the spectrometer had to be kept energised if the instrument was to function continuously.

Deciding that the system must be kept running continuously, a telephone monitoring system was devised to eliminate the need for the week-end inspections. Now, when the pilot plant supervisor wishes to find out "how things are" with the spectrometer, he picks-up his home telephone receiver, dials the plant number and listens in. At the plant-end of the line, the receiver is automaticaly raised and a sequence of signals are transmitted. From these, the supervisor can tell how the unit is faring. For instance, the instrument circuit, the dry-ice trap, the liquid nitrogen trap and the vacuum gauge each have their own separate coded signal. In the case of the traps, a rising temperature produces a note of a different pitch from that corresponding to that given for normal and proper functioning. Similarly, for a drop in vacuum, a warning dissimilar from that given during normal vacuum is produced. Thus the supervisor can now easily tell when trouble is brewing at the plant, no matter what his location, as long as he can reach a telephone.

# World of CHEMICALS

### Iraq Loan to Jordan

The Iraq Council of Ministers are to make a loan of £1 million to Jordan for a superphosphate project. The reason for the loan is to circumvent the floating of a company for the project—which would reap most of the profit—and thus provide much needed development funds for Jordan.

### Fertiliser Plant for Egypt

A contract for a chemical fertiliser plant was recently signed by the Egyptian deputy Prime Minister. Worth some £22 million, the plant will be built by a group of French and West German firms at Aswan, Upper Egypt.

### Kaohsiung's New Refining Plant

A new catalytic refining unit, purchased through a loan from the Gulf Oil Co., has enabled an increase in the efficiency of the Kaohsiung (Formosa) petroleum refinery. The Chinese Chemical Petroleum Co., will in consequence make 80 octane petrol available at all their stations throughout the island instead of at Taipei and Keelung as at present. Another new addition to the refinery is a cracking unit.

### Portuguese Factory Extension

An extension to Amoniaco Portugal's factory at Estarreja will allow for a total production of 70,000 tons of sulphate of ammonia per annum by 1958 or 1959. The total estimated cost of the extension is some £1½ million. Local supplies of anthracite and lignite will be used to obtain hydrogen.

### Refractory Plant for India

An Indian refractory plant with a capacity of about 120,000 tons is expected to be in commission by Tata by 1958. This will be the result of an agreement entered into by Tata with Didier Werke of Germany.

### Turkey's Cement Factories

Turkey announces that five state cement factories with a total capacity of 490,000 tons are due for completion this year. Turkey hopes that local industry will meet home requirements by 1957.

### Cuban Oil Refinery

A new $10 million refinery being built by the National Petroleum Corporation of Cuba will, it is hoped, be producing 5,000 barrels a day by the end of this year. Cuba's crude oil output had risen to 1,500 barrels a day at the end of 1955—less than 3 per cent of the national consumption.

### Two Years=$1.6 Billion

The annual survey of the Manufacturing Chemists Association of America states that expansion plans of the American chemical industry will total $1.6 billion, in the next two years. They also report that construction projects completed during 1955 totalled $772 million. The survey shows that organic chemicals will absorb the major share of the invested capital with fertiliser chemicals, metals, plastics and resins, inorganic chemicals, rubber, textile fibres, and the petroleum and natural gas industries following in the order given. Laboratories is last on the list.

### New Guinea Exploration

The Netherlands New Guinea Oil Co. plan a request for a further 17 million hectares of its concession for the exploration of oil in New Guinea. Should the Dutch Government approve, practically the whole of the Netherlands New Guinea will be within the concessional area of the company.

### Congolese Pyrethrin Plant

A plant for the production of pyrethrin extracts from pyrethrum flowers is to be erected at Goma, in the Belgian Congo. The capacity of the plant will enable 2,400 tons annually of dried pyrethrum flowers to be treated, from which the raw and refined pyrethrin extracts will be produced. The plant is being erected for the Société pour le Traitement des Produits Agricoles au Kivu by the Engineering Division of the Société Belge de l'Azote et des Produits Chimiques du Marly, of Liege, Belgium.

### Rumania Rigs India

Rumania and India have signed an agreement under which India will purchase oil drilling rig from Rumania. The value of the agreement is reported to be worth some £336,000 and includes technical services. The rig will be used in the Jwalamukhi area in the Punjab hills.

### Europe's Longest Pipeline

What is claimed to be the longest underwater pipeline was recently opened at Ravenna. The link is approximately seven miles long, of which over three miles is underground and four miles under water leading to an artificial island off Punta Marina on the coast.

### Cyclops Nickel and Cobalt Find

A report made in 1952 by the Dutch New Guinea Commission and just publicly released, states that rich resources of nickel and cobalt have been found in the Cyclops mountains in New Guinea and on some islands off the coast of Vogelkop.

### Belgian Desulphuriser

M. W. Kellogg Company expect to bring on stream at the end of 1956 a catalytic desulphuriser and reformer for Raffinerie Belge de Petroles, Antwerp, using a platinum.

### Mexican Fertilisers

A new fertiliser plant for the Mexican Government-owned fertiliser company, Guanos y Fertilizantes, will be inaugurated in Cuautitlan, near to Coatzacoalcos and Minatitlan, the sulphur zone, in the early part of 1956. The annual capacity of the plant will be in the neighbourhood of 80,000 tons.

### Italian Oil Loan

The State-owned oil corporation Ente Nazionale Idrocarburi has been authorised by the Italian Government to float a loan for £34 million. The loan is to enable ENI to finance its new plant for the production of fertilisers, synthetic rubber from natural gas, and for oil prospecting in central and southern Italy. The new plant is to be erected at Ravenna.

### Methanol Plant for U.S.A.

A new plant which will produce some seven million gallons of methanol annually is to be erected by the Hercules Powder Company of America. The plant will cost about $2 million and will be situated at Louisiana, Mo. The process to be used at the new plant will be that of the Swiss "Inventa"; the first time ever to be used in the United States.

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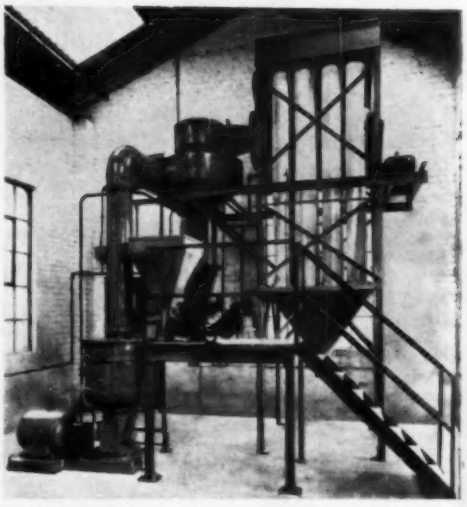
# PLANT EQUIPMENT NEWS

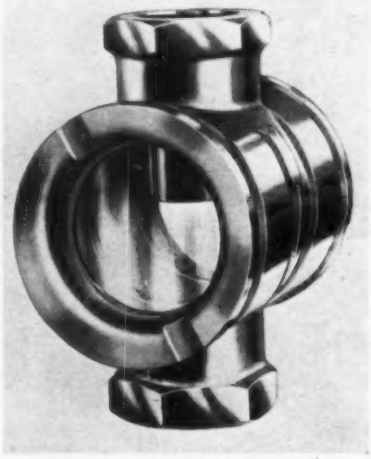
## Mill Suitable for Wide Range of Materials



A Superkek Mill suitable for a wide range of materials, for which figures provided by independent analyses are given, for example, lactose 95.5% through 170 B.S.S. mesh and D.D.T. 90.7% through 325 BSS mesh, 95.4% through 300 BSS mesh.

The mill is an adaptation of the well-known Kek pin-disc pulveriser, and provides for integral air classification of the product. The mill fan blades, fitted to the underside of the rotating disc of the mill carrying one set of the grinding pins, set up an air flow which takes away the powdered material as it is ground and delivered from the discs. The air current, together with entrained powder, passes up through the annular space formed between the enclosing casing and an internal hopper. By deflection at the top of the casing, the heavier powder is caused to fall into the hopper, whilst the air current carrying the superfine powder leaves the selector chamber. The hopper also acts as a feeder to the grinding discs, being itself fed from an outside pipe shute. The fine powder is finally collected by a cyclone and fan. Alternatively, a closed-circuit grinding system may be used; in this way an inert atmosphere may be provided for explosive materials. **Kek Ltd., Palmerston Street, Ancoats, Manchester 12.**
BCE 69

## Flow Indicating Device —Recommended for Gravity Lines



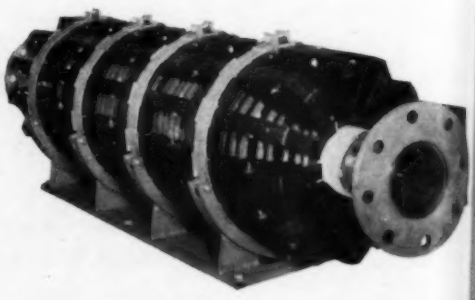
A new flow indicating device for use on cooling water lines, oil lines, and for a variety of other systems is now being manufactured, at present, in ¾ in. pipe sizes. Known as the Fig. 55A Bowser Flow Sight, it is made in bronze and is of the double window clear vision type. It is equipped with a nozzle on the inlet side to cause the liquid to flow downward in a round stream without contacting the glasses. The Fig. 55A is recommended for use on gravity lines where the flow is vertically downwards. It can also be used on pressure lines for observing the clarity of the liquid.

An important feature is the method of retaining the glass; the retainer, being threaded on the outside, permits rapid and uniform circumferential tightening. There are no bolts to cause uneven pressure and resulting glass breakage. Larger sizes other than ¾ in. are envisaged and in other materials. Maximum pressure for the standard model is 125 psi, it is fitted with heavy plate glass. **Liquid Systems Ltd., Union Road, Croydon, Surrey.**
BCE 70

## Liquid Metal Pumps for Nuclear Power Plants

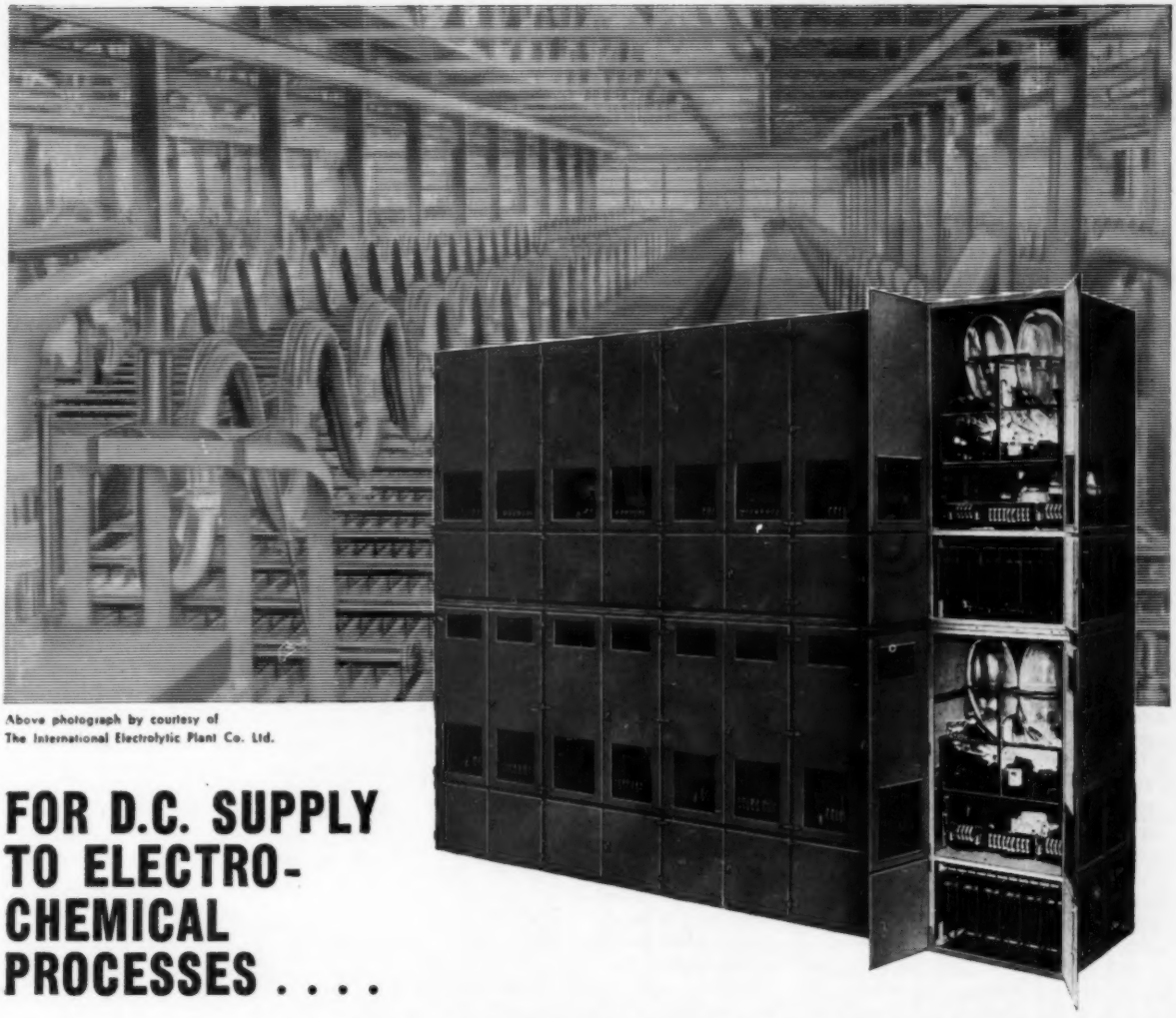
Sodium, sodium - potassium and lithium make a group of liquid metals which are likely to be used mainly as coolants in nuclear energy applications where high rates of heat transfer are necessary at a high temperature. Bismuth is also likely to be useful. These two classes of liquid metal —the low density, viscosity and resistivity metals like sodium, and the high density, viscosity and resistivity metals like bismuth or mercury—usually require different methods of pumping.

Two British companies announce the development of electromagnetic pumps for such applications. These are, namely, The British Thomson-Houston Co. Ltd., and the English Electric Co. Ltd. The lower illustration shows the B.T.H. pump with cover removed. **The British Thomson-Houston Co. Ltd., Rugby. The English Electric Co. Ltd., Marconi House, Strand, W.C.2.**
BCE 72



## System for Fine Temperature Control

Designed to provide a simple and reliable control system for the fine degree of temperature control required by many processes, the Foster temperature indicating controller incorporating an electronic control system is suitable for use in conjunction with electrical resistance thermometers, thermocouples, or radiation receiving tubes so that by the use of appropriate elements, temperature ranges from −200°C up to 2,000°C may be controlled. The electronic operation gives immediate correcting action to control condition. The three operating units comprising the controller can be withdrawn from the front of the instrument in a few seconds. **Foster Instrument Co. Ltd., Letchworth, Herts.**
BCE 71



Above photograph by courtesy of
The International Electrolytic Plant Co. Ltd.

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Hewittic Rectifiers have proved to be the ideal converting plant for supplying electro-chemical processes. Apart from ease of installation, simplicity and reliability they afford maximum efficiency and economy in operation, operate entirely unattended and require practically no maintenance. Individual cubicles can be isolated for inspection without appreciably affecting the total capacity of the plant.

The equipment illustrated is one of a number of Hewittic 8,000 amp rectifiers to be banked together to provide outputs of many times this capacity.

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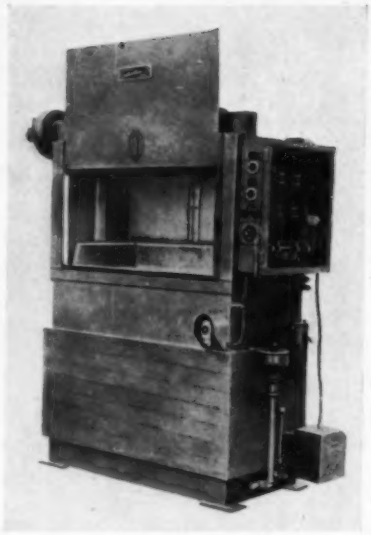
## Perlift means Automatic Degreasing and Drying

In every section of industry in which metal components are manufactured the metal surfaces become contaminated with grease which must be removed before surface coatings can be satisfactorily applied. A convenient method of degreasing which has been employed for some considerable time is that involving the use of trichlorethylene vapour. This process has the advantage of being simple to control, the work is left in a dry condition and a minimum of space is required. However, the usual degreasing equipment of the open-top, manually operated type has two serious disadvantages: there is loss of the toxic triochlorethylene solvent and the efficiency of the process must depend entirely upon the conscientiousness of the operator.

A machine which has been especially designed to overcome these disadvantages has recently become available. Known as the Perlift, it has a totally enclosed construction and an automatic time cycle, consisting of an evaporating tank, with a thermostatically controlled electric heating system, a vapour chamber and an electrically operated platform hoist. It is available in three standard sizes although non-standard machines can be built to order.

The operator has only to place the work on the platform and press the operating button. The sliding door of the machine is automatically closed, lowering the platform into the vapour chamber, where the component resting



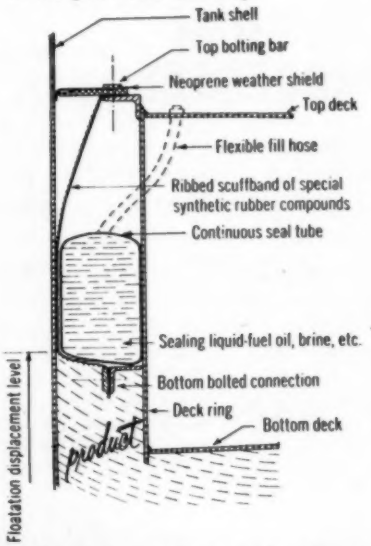
on it is degreased by the rising trichlorethylene vapour. When the vapour has risen above the level of the work, a temperature-controlled time mechanism causes the platform to rise through the drying zone into the unload position. At the same time, the sliding door opens and a bell signals the end of the sequence.

The degreasing and drying cycles are, therefore, quite clearly independent of the operator and are automatically governed by the quantity of work in the machine. No fumes can escape while the Perlift is in operation as the sliding door is closed. When the door is opened a suction fan prevents the fumes from entering the room. **The Electro - Chemical Engineering Co. Ltd., Weybridge.**
BCE 73

## A Rubber Tyre 80 ft. in Diameter

An entirely new method of eliminating vapour loss in large petroleum tanks is made possible by what is virtually a rubber tyre 80 ft. in diameter by 30 ft. high. This new method of sealing has just been incorporated in two tanks recently completed for Mobil Oil's Refinery at Coryton, Essex.

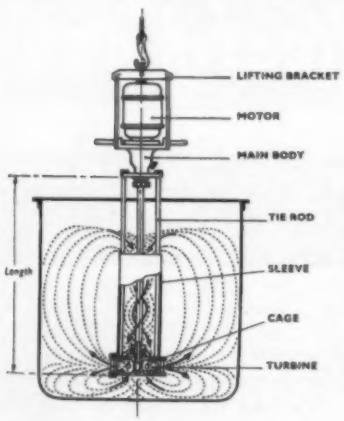
The two tanks, which each hold over 1 million gallons of petroleum product, have twin skin steel floating roofs which float up and down on the surface of the liquid stored. Between the floating roof and the tank wall is fitted a huge 80 ft. diameter tyre made of Nylon fabric base, coated on each side with butadiene acrylonitrile synthetic rubber. This tyre is partly inflated with liquid and secured to the floating roof of the tank, thereby preventing vapour from forming, and acting as a complete seal between the floating roof and the wall of the tank at all times. The rubber tube, which is protected with a similar synthetic rubber scuff band, rises and falls with the steel roof on the level of petroleum product. It thus provides a complete vapour free seal. This new method of sealing hydro carbon products is the first of its kind in Europe, and has aroused considerable interest in the petroleum industry.




The design is built under licence from The Hammond Iron Works, U.S.A., by Wm. Neill & Son (St. Helens) Ltd., who feel confident that this new design eliminates difficulties experienced in the past with floating roof tanks. **Wm. Neil & Son (St. Helens) Ltd., 38 Victoria Street, Westminster, London, S.W.1.**
BCE 75

## High Speed Mixer and Dispenser

A portable turbine mixer (the Ultramix) is a dispenser of new design and with a wide range of possible use, not only in the paint industries, but also for those applications of emulsification and gas and solid dispersion and mixing. The Ultramix has a number of interesting features, among which are a draught tube or sleeve surrounding the impeller shaft, a double-suction high-speed impeller, and a grid formed by cylindrical bars surrounding the impeller for both liquid impact and shear. The accompanying diagram illustrates the method and operating principles of the machine. The machine is available in mild or stainless steel, and is listed in eight models according to capacity, and also to maximum horse-power of duty (i.e., ½, 2, 7½, 15 h.p.). Thus, a capacity range from 1-2,600 gallons is covered. **Vickers-Armstrong (Engineers) Ltd., Vickers House, Broadway, Westminster, London, S.W.1.**
BCE 74



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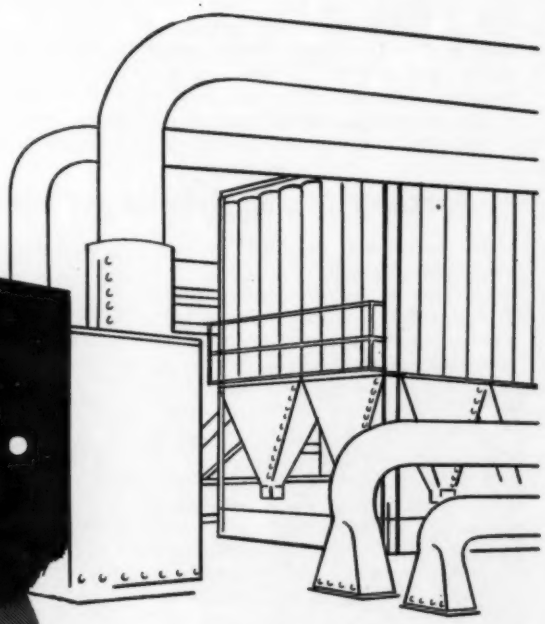

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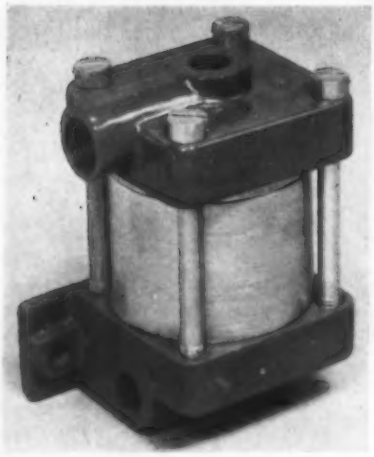
## Higher Pressures and Flow Rates of Fluids Possible



Electromagnetic valves of the "glandless" poppet type, employing a new type of actuator of advanced design and performance and stated to be capable of handling fluids at higher pressures and flow rates than has previously been possible, are now available in balanced and unbalanced versions. Both utilise the same electromagnetic actuator, but are fitted with slightly different valve mechanisms.

The unbalanced version (Type V7/11) has a full bore capacity of 3/32 in. and will handle compressed air or hydraulic oil at working pressures up to 150 lb./sq. in. The balanced version (Type V23/11) has a full bore capacity of 3/16 in. and will handle either of the above working fluids at pressures up to 100 lb./sq. in. Both may be used for vacuum service.

Both versions are of the three-way type, and may either be used to control small single acting power cylinders directly, or used to operate larger capacity three-way or four-way directional control valves where power cylinders of larger size and stroke are involved. The valve body and top cover are made in bronze or brass, and the entire magnetic circuit including the armature is in mild steel. All ferrous components throughout the whole unit are electroplated to prevent corrosion. The valve seat is made of soft oil and water resistant synthetic rubber, bonded to the armature. **Baldwin Instrument Co. Ltd., Brookland Works, Dartford, Kent.**
BCE 76

## Transaire Solves Fluid Flow Problem

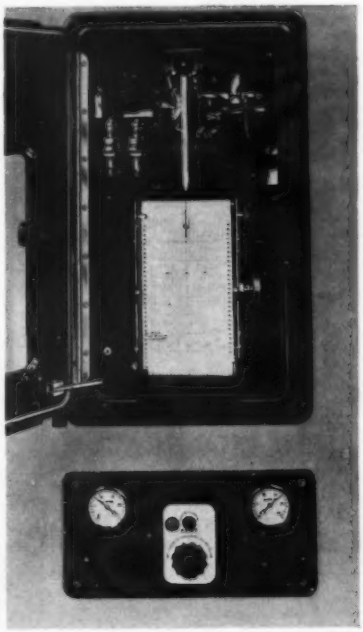
A differential pressure transmitter which is reported to be the answer to the problem of close coupled fluid flow measurement, liquid level or any other installation requiring differential pressure measurement and transmission is the Transaire. It has many advantages, amongst which are: no levelling—mercuryless dry meter; light weight for easy handling; weighs only 23 lb.; self-draining or venting—no periodic manual venting or draining; flexible, but tough Teflon-coated glass fabric diaphragm; hydraulic damping assures stable air output from transmitter; and force-balance construction The Transaire has a 1,500 psi pressure rating and is available in two ranges, 20-200 in. and 80-800 in. of water. **Taylor-Short & Mason Ltd., Hale End Road, Walthamstow, London, E.17.**
BCE 77

## Factory Gas Supply Controlled by Wobbe

An instrument designed for the automatic control of supplies of town's gas in factories to a desired Wobbe Index by either automatically adding a small amount of air to the incoming gas or trimming the output of a mechanical mixing machine by an additional supply of gas has been developed by the Sigma Instrument Co., and George Kent Ltd.

New and highly critical industrial processes involving the use of town's gas are continually being developed giving higher rates of production and accuracy of working; small changes in gas characteristics, particularly specific gravity, which were previously unnoticed, have caused serious difficulties. The Wobbe Index Controller is stated to be the answer to problems that have arisen.

Gas is usually supplied to the machines under pressure locally boosted, and the primary air added near the burner by injection, or mixed mechanically before entering the factory mains. This machinery can now be controlled more accurately and with higher rates of working, because the Wobbe Index Controller enables a perfectly constant heat transfer to be obtained at the gas burners. **George Kent Limited, Luton, Bedfordshire.**
BCE 78



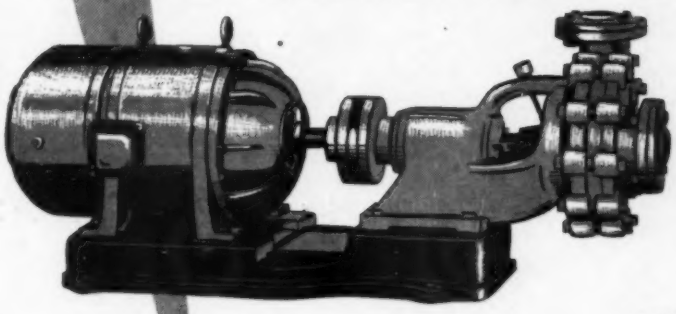
## Major Advance in Respiratory Protection

The new Dustfoe 55 represents a major advance in respiratory protection and it should find numerous applications within the chemical industry. Its light weight (less than 3 oz.) and low breathing resistance give the highest degree of user-comfort. The 50% reduction in width of the filter holder eliminates a "blind-spot" area, and greatly increases the downward vision. This change also results in better balance.

The filter is made of charged resin-treated felt. A change is induced on dust particles coming in contact with the filter by the dipole formed by the charged resin and fibre of the felt, promoting electrostatic retention of dust and supplementing the mechanical filtering action of the maze of fibres. No prefilter is required; the one medium does the complete job. The filter is pre-formed for accurate fit, and is positioned by studs on the holder.

Changing filters is the work of a moment and the exposed filter edges permit visual inspection, assuring a positive seal. Air intake is located at the lowest point of the respirator. Counter-gravity flow of inhaled air cuts down on the entry of heavier dust particles into filter. The aluminium facepiece can be formed with the fingers to conform to the face and the final fit and seal is provided for by the sponge face cushion. The new Dustfoe 55 is but one of a considerable range of respiratory devices for various industrial purposes manufactured by the **Mine Safety Appliances Co. Ltd., Queenslie Industrial Estate, Glasgow, E.2.**
BCE 79

# PUMPS FOR THE CHEMICAL INDUSTRY



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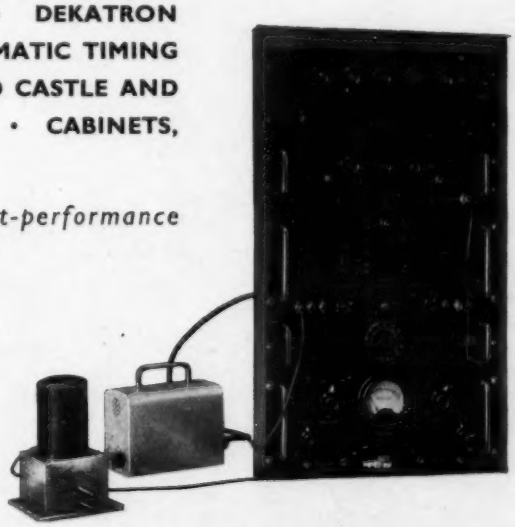

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# Book Reviews

**Synthetic Ion - Exchangers Recent Developments in Theory and Application**

by G. H. Osborn, F.R.I.C.

419 pp., illustrated. 8¼ x 5¼ in. Chapman and Hall Ltd., London. Macmillan Co., New York, 1955. 30s.

THE first three chapters of the book deal briefly with the general properties and analytical aspects of ion-exchangers and include a somewhat sketchy treatment of recent theoretical developments and a chapter on performance data of commercially available resins. A useful amount of information about the performance of a range of resins supplied by one American manufacturer is given, but the performance data tabulated on other manufacturers' products is very limited and hardly justifies its inclusion. Most readers will find the data sheets supplied by the manufacturers more informative.

The remainder of the book is devoted to chapters on the more recent developments of ion-exchange such as, reactions with materials of low solubility, ion-exclusion, ion-exchange membranes, and therapeutic applications. The chapter on ion-exchange membranes is essentially a reproduction of a paper by Winger, Bodamer and Kunin and it is to be regretted that the author includes no discussion or comments of his own on the paper. The subjects of ion-exclusion and the reaction of ion-exchangers with materials of low solubility are dealt with more completely and critically.

The most noteworthy feature of this book is the bibliography which occupies some 103 pages of the 419 constituting the book. The bibliography is reasonably complete but there are significant omissions, particularly of papers published since 1952. Readers concerned with some specific application of ion-exchange will find the method of indexing under elements and compounds very useful.

R. A. Wells

**The Principles of Chemical Equilibrium with applications in Chemistry and Chemical Engineering**

by K. G. Denbigh

514 pp., illustrated. 8¾ x 5¾ in. Cambridge University Press, London. 1955. Price 42s.

THE avowed aim of this book is that of acting as a text in thermodynamics for university students of chemistry and chemical engineering. A special feature claimed is the inclusion of a number of selected problems to illustrate principles covered in the text. A nod is made to chemical engineers by the occasional use of the word "liquor" instead of "solution" in some of these problems. The latter, however, are generally of a familiar type and do not constitute a large part of the book.

No particular emphasis on applied thermodynamics has been given in the text. This is probably a wise decision as the basic need in the education of both engineers and chemists is for a better understanding of thermodynamic principles. On such a platform, a familiarity with the application of thermodynamics to a specific branch of engineering or chemistry may be built by the "problem method". The fruits of an early specialisation are only too evident in the gulf which exists between thermodynamics as taught to chemists and to engineers in many of our educational institutions. Chemical engineering, with a foot in both camps and young enough not to have already embarked on a set course still has the opportunity of deciding its own policy. Few can doubt that classical chemical thermodynamics is the proper base on which to build for the future, provided that such a course is supported by problem classes in which applications are demonstrated. Chemical thermodynamics is not a subject which is growing rapidly; the subject has appeared to be almost complete and sufficient for a considerable number of years even though techniques of measurement of fundamental quantities have been improved.

Many text-books have appeared. This fact is perhaps a measure of the difficulties experienced in teaching the subject which seems, by its very concentration on simple and largely familiar ideas of the properties of energy, to confound the new student. In approaching a new subject we tend to relate our newly acquired knowledge to common experience, and by a process of analogy form a picture which we can accept. Thus we may think of kinetics in terms of billiard balls moving indefinitely, and perhaps on occasions sticking together. However when a subject, new to us, relates to common experience itself, there is nothing left with which an analogy may be drawn. Possibly for this reason it seems that thermodynamics will always offer the greatest possible challenge to the teacher or writer of text-books. Among text-books, there is little variety of content but a much greater variety in presentation. It has always seemed that no one text-book, by itself, was completely satisfying. A new appreciation always came from reading another book; the same content was there but viewed from another angle. The book under review presents some new angles of vision. Is it complete in itself? The answer to this must eventually lie in its effect on new, rather than old students of thermodynamics.

The book is divided into three parts. In Part I, the first and second laws are explained and the criteria for equilibrium developed. Part II is concerned with the details of reaction and phase equilibria. Part III introduces statistical thermodynamics and the third law. The thermodynamic restrictions on kinetic equations are also briefly outlined in the latter section. No great mathematical ability is required to follow any part of the book. The style is pleasant and the development of concepts orderly and logical. Many of the problems which have been taken from past examination papers of Cambridge University form a useful addition to the lecturer's collection. The author has chosen to discuss the thermodynamics of galvanic cells and of surface phenomena in only the brifest fashion.

In the preface, the author affirms that thermodynamics needs to be studied, not once, but several times at advancing levels. This is undoubtedly true. While chemical engineers will be reluctant to accept the new book as an alternative to that of Dodge, they should certainly welcome it as providing the best available introduction to it.

P. H. Calderbank

**Atom Harvest**

by Leonard Bertin

253 pp., illustrated. 8¼ x 5¼ in. Secker and Warberg, London, 1955. 20s.

TECHNICAL people are usually stumped when their friends ask them for a title of a book about atomic energy that will not be above their heads. This volume can be recommended for the broad over-all picture it gives of British achievements; it does for our atomic project what Gordon Dean's *Report on The Atom* did for the American. Well brought out is the fact that future developments depend to a great extent upon the engineers, and the chemical engineers in particular.

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# The Month's News in Brief

## Chemicals, Plant and the Atom at the B.I.F.

Over 100 members of the Association of British Chemical Manufacturers will be represented at the British Industries Fair, Olympia, from 23 April to 4 May this year. The Chemical Section, which is being organised by the Association and will occupy some 50,000 sq. ft. of floor area in the National Hall (see illustration this page), will have a special decor and layout. The exhibits promise much in the way of originality and many new items are expected to make their début during the course of the exhibition.

Castle Bromwich will house the chemical engineering exhibits, and pre-exhibition announcements from chemical plant manufacturers illustrate that they will be well represented at this venue.

The atom, too, will be a major feature of the B.I.F. This will form part of the electrical section at Olympia and will consist of the "Atoms for Britain" Exhibition first presented by the UKAEA at Geneva. Covering some 7,000 sq. ft., the exhibit will consist of models, films, diagrams and sample apparatus which will illustrate Britain's progress in harnessing atomic energy in industry, agriculture and medicine.

## News Briefs

**The total now** subscribed to the Industrial Fund for the Advancement of Scientific Education in Schools now stands at some £2,900,000. Of the 90 companies contributing, about a third are firms actively engaged or allied to the chemical industry.

**The British Oxygen Company** have built a new works on a six-acre site in the Milton of Craigie area of Dundee. It is capable of compressing 500,000 cu. ft. of oxygen per week into cylinders for distribution to customers.

**The recently published** text of the Department of Scientific and Industrial Research Bill discloses that the present Advisory Council for Scientific and Industrial Research is to be replaced by an executive council to be known as the Research Council. The Bill has been introduced in the House of Lords.

**What is believed** to be the first recorded death from berylliosis (beryllium poisoning) on a death certificate resulted from an inquest held recently at Newcastle upon Tyne. The verdict was returned on Mrs. A. J. Atkinson, a research worker on beryllium, who became so allergic to the substance that it gradually destroyed her lungs.

**I.C.I. recently** announced that the emulsion P.V.C. polymer made by their Plastics Division is being reduced by 1d. per lb. to 1s. 8d. per lb. The reduction took effect from 19th March.

**English Electric** have extended their comprehensive computing service by starting a new centre in their London Office, Marconi House, Strand, W.C.2. This service, which is available to organisations outside the English Electric Group, is provided by the DEUCE (digital electronic universal calculating engine). The computing service has behind it a unique and extensive library of programmes and sub-routines which have previously been prepared for the solution of many and varied problems. This library is compiled from all establishments who are using the DEUCE extensively and will be available to those using this new computing service in London.

**British Carbo Norit Union Ltd.** and Whessoe Ltd. announce that they have completed an agreement for the supply of Carbo-Union-Whessoe Recovery Plant for the purification of gases and the recovery of vapour phase solvents.

**See You At Stand C112**

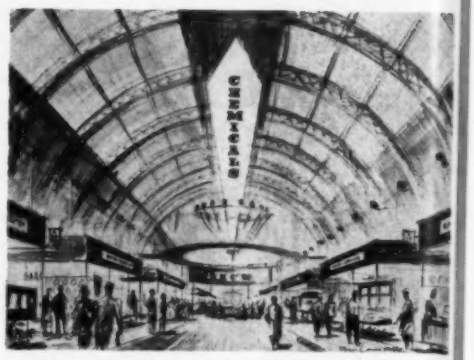
Considered by many to be one of the largest chemical shows yet held in this country, the chemical industry's exhibits at both the London and Castle Bromwich Sections of this year's B.I.F. will hold much of interest for our readers. *British Chemical Engineering*, too, will be represented at the London Section of the Fair—Stand C112—and an open invitation is extended to all our readers to avail themselves of the services of this journal's representatives.

**The O.E.E.C. Gas Committee** held its first session recently. The setting up of this Committee emphasises the increasingly important part which the gas industry will have to play in the energy economy of Western Europe.

**The Board of Trade** announce that with effect from 3rd April, 1956, their Standards Department will revert to its former title of "Standard Weights and Measures Department."

## Atomics

**After demonstrating** industrial television to the Atomic Energy Authority last year, Pye Ltd. were given a contract to design a special camera capable of being used inside an atomic reactor at the Authority's Cumberland factory. This has now been completed and has been delivered to Harwell for tests prior to its use at Calder Hall. A second camera, which is now being made, is to be supplied to the Authority within the next six months and will be used as a standby.




*Artists impression of the Chemical Section, National Hall, Olympia.*

**The Ohio Oil Co.** of America are reported to be experimenting with a process designed to recover uranium from lignite (brown coal) which will prove to be economical enough to sell the uranium recovered.

**An international** atomic energy exhibition is to be held near the Schiphol aerodrome, Amsterdam, in 1957.

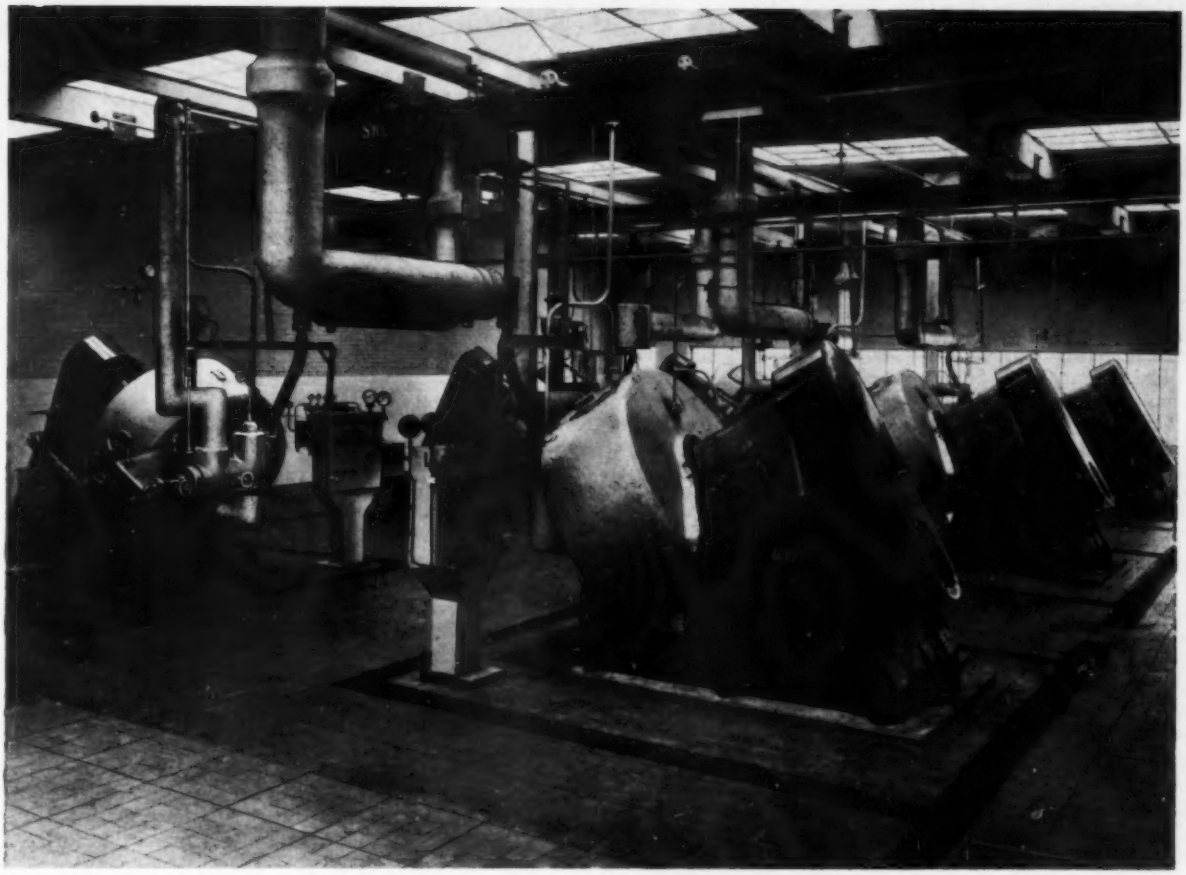
**W. H. A. Robertson & Co.,** of Bedford, have received an order from The Swedish Atomic Energy Co. for a uranium rolling mill.

**Uranium - bearing minerals** are reported to have been found in the Maritime Alps of Italy.

**Sixteen tons** of heavy water have already been shipped overseas as part of the U.S. "atoms for peace" programme for assisting foreign countries. Eleven tons have been sent to Britain, and five to France. In all the export of 129 tons has been approved, including a total of 50 tons for Britain, 30 tons for France, 21 tons for India, 11 tons for Australia, 10 tons for Italy, 7 tons for Switzerland.

**Kema N. V. of Arnhem,** a semi-official electro-technical research body, are building a large laboratory for nuclear research near Arnhem on the site of their existing laboratories. This is independent of the plans for one large Dutch centre for nuclear research (the R.C.N., Reactor Centre Netherlands).

**The United Kingdom Atomic Energy** Authority have, with the consent of the Government of the



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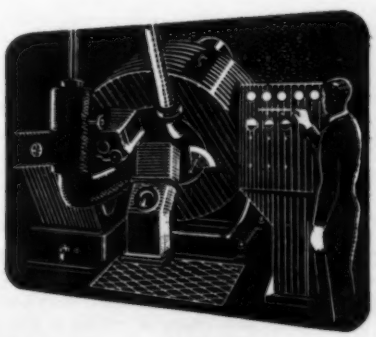

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Commonwealth of Australia, entered into a contract with Mary Kathleen Uranium Ltd., to buy for a number of years uranium concentrates to be produced in the Mary Kathleen mine in North-West Queensland.

**Several Finnish industries** are showing considerable interest in atomic energy and two companies have been formed to study questions relating to its utilisation for heating, power and lighting. Finnish electricity experts, pointing to the inadequate Finnish resources of hydro-electric power, and of the increasing cost of coal for steam-power, have indicated that Finland may have to rely on atomic power stations in the foreseeable future.

**The Atomic Energy Authority** are acquiring two built-up areas on Grove Airfield, near Wantage, as a site for a small outstation of the Atomic Energy Research Establishment, Harwell. These two areas are part of the airfield which the Air Ministry had decided to relinquish. The new outstation is mainly to provide laboratories to allow the Technological Irradiation Group to develop more rapidly.

**The President** of the American and Foreign Power Corporation announced that one of the three atomic power stations his company plans to construct in Latin America will probably be set up in Sao Paulo. A contract for the supply of the research reactor has been provisionally awarded to the Babcock & Wilcox Company of New York.

**The new Asian** nuclear centre, which it was decided to establish at the Colombo Plan meeting last October, will be sited in the Philippines. Detailed plans are now being elaborated and will be completed by this autumn. The United States is expected to contribute $20 million towards its costs.

## Contracts

**G. & J. Weir Ltd.** have secured a contract through Singmaster and Breyer, of New York, for one of the largest sea-water evaporating and distilling plants in the world. This export order is worth about £1¼ million. For installation at Aruba, Netherlands Antilles, the sea-water evaporating plant will provide 8,000 tons (1,792,000 gallons) of fresh water a day. Not only is this the largest individual contract ever received by Weir's, but the plant, when completed in 1958, will be one of the largest in the world.

**I.C.I. have received** the approval of the Government of India to a project for the manufacture of polythene in India. The manufacture will be undertaken by the I.C.I. associate, The Alkali & Chemical Corporation of India Ltd., in which the Indian public has a substantial shareholding. The project will involve a total investment of some £2¼ million.

**The engineering** of the offsite facilities required in connection with the £26,000,000 expansion programme recently announced by The British Petroleum Co. Ltd., for their Kent Oil Refinery has been awarded jointly to W. J. Fraser & Co. Ltd. and The Power-Gas Corp., Ltd.

**An order has been received** by Brown Fintube (G.B.) Ltd. from the Kellogg International Corporation for a quantity of multiple section heat exchangers, to be used in the processing of hydro-carbon gases of relatively low molecular weight at the Wilton Works of I.C.I.

**Recent orders** for Petro-Chem Iso-Flow Furnaces placed with the British Licensees, Birwelco Ltd., include units for installation at Bahrein, Grangemouth, Stanlow and Ellesmere Port.

**The British Aluminium Company's** subsidiary, Canadian British Aluminium Co. Ltd., is placing orders valued at £2,250,000 with two British companies for electric conversion equipment for a new smelting plant at Baiecomeau, Quebec. A £1,750,000 contract is being placed with British Thomson-Houston, and one of £500,000 with the English Electric Company.

**Woodall-Duckham Construction** has received from Appleby-Frodingham Steel Company (a branch of the United Steel Companies) an order valued at about £2 million for a further coke oven and by-product plant to be built at Scunthorpe, Lincolnshire.

## People

**Reginald S. Medlock**, B.Sc., A.R.I.C., A.M.I.C.E., A.M.I.Mech.E., has been appointed to the board of George Kent Ltd.

Fellows elected to The Royal Society for 1956, include: **Prof. J. F. Baker**, Cambridge University; **Prof. R. M. Maling**, Imperial College of Science and Technology, London; and **Dr. N. Kurti**, University of Oxford and Senior Research Fellow, Brasenose College.

**Dr. B. F. J. Schouland**, deputy director of the A.E.R.E., has been appointed by the Minister of Fuel and Power as a member of the Scientific Advisory Council.

**Mr. J. K. Batty,** joint managing director of the Alkali Division of I.C.I., has been appointed Alkali Division chairman, in succession to **Mr. W. M. Inman** who has retired.

**Dr. Kenneth Mees** has retired from the position of vice-president in charge of research of the Eastman Kodak Company. He is succeeded by **Dr. Cyril J. Stand**.

Managing director of The British Oxygen Co. Ltd. since 1938, **Mr. W. W. Watt** retired on 31st March last having reached the age of 65. Born in Glasgow, Mr. Watt spent 33 years in the soap industry being chairman and managing director of Ogston and Tennant Ltd., Scotland, and later vice-chairman of Port-Sunlight for three years before joining B.O.C.

*W. W. Watt.*

*Sir Miles Thomas*

**Sir Miles Thomas,** who has resigned the chairmanship of the British Overseas Airway Corporation, has been appointed a director of Monsanto Chemicals Ltd., and will become chairman of the company not later than 1st July, 1956. He will succeed **Mr. E. A. O'Neal, Jr.,** who is a director of Monsanto Chemical Company the American firm, remains a director of Monsanto Chemicals Ltd.

## Coming Events

**April:** The Houston World Oil Exposition and Convention is to be held this year from 25th to 29th April at the Sam Houston Coliseum and Show Grounds. Further details may be obtained from: World Oil Exposition, 1607, Jefferson, P.O. Box 3105, Houston, Texas.

**April:** First National Industrial Textile Trade Fair is to be held at the Royal Albert Hall, London, from 23rd to 27th April, 1956.

**May:** A further Welding Design Course to assist draughtsmen and designers of welded structures and fabrications, will commence on Monday, 14th May, at the Head Office of Quasi-Arc Ltd. in Bilston, Staffordshire. The course lasts for one week. Further details, together with the enrolment form, can be obtained from the Constructional Design Department at Bilston.

**May:** The Physical Society's Exhibition of Scientific Instruments and Apparatus will be opened by Sir John Cockcroft. The exhibition will be held in the New Hall of the Royal Horticultural Society from 14th to 17th May, 1956.